SPOKANE PM_{10} ATTAINMENT PLAN

Appendix K

Dispersion Modelling and Attainment Demonstration

Spokane County Particulate Matter (PM_{10}) Nonattainment Area

Dispersion Modelling / Attainment Demonstration

Prepared by Clint Bowman
Washington State Department of Ecology
Air Quality Program

September 1994

Table of Contents

Figures

Tables

INTRODUCTION

This appendix describes the technical approach taken to model the Spokane PM_{10} non-attainment area and to evaluate the proposed control strategies that will be used to bring the area into attainment. Both point and area sources are significant emitters of PM_{10} and are modelled using separate models; ISC2 for point sources and WYNDValley for the area sources. The actual emissions are used in the model validation; maximum potential emissions are used in assessing the control strategies. Point sources include all building wake effects where applicable. The area sources are described with a spatial resolution of 1 km and, where applicable, a temporal resolution of 1 hour. The time variability of area sources was based on available survey results, traffic counts, and heating degree-day calculations. Emission rates from sources that would be affected by the presence of moisture, e.g. paved and unpaved roads, were also modified based on available meteorological data.

Model output was produced by combining the output of the two models with a background PM_{10} concentration which was derived from either monitored values at Turnbull Slough, a remote monitoring location approximately 25 miles southwest of Spokane, or the climatological mean concentration for the day of year based on more than 20 years of particulate monitoring at the same site. Unless otherwise stated all references to modelled concentration refer to the sum of point, area, and background concentrations.

Attainment determination was based on the second high modelled value for each 1 km cell within the non-attainment area. Attainment was declared when none of the cells within the valid modelling area exceeded 150 $\mu g/m^3$ for a 24-hour average. Attainment was evaluated using the maximum potential emission rates for point sources and the actual emission rates for area sources.

AMBIENT CONCENTRATION

The analysis of the PM_{10} concentrations in Spokane began in 1987 with the designation of the area as non-attainment for PM_{10}. At that time it was decided to use only two years of data (1985 and 1986) in writing the SIP. As the process continued and the Clean Air Amendments of 1990 changed some of the ground rules for completing PM_{10} SIPs, the analysis was broadened to include the period 1987 through 1989. A total of 72 days were identified as having concentrations higher than 120 $\mu g/m^3$, a level which was picked as being sufficiently low as to produce a statistically large data set yet high enough to be associated with the same conditions which produce concentrations greater than the 24-hour National Ambient Air Quality Standard of 150 $\mu g/m^3$.

It is thought that the data set represents some of the worst PM_{10} episodes that could be expected to affect Spokane as well as a complete description of the different meteorological conditions associated with high PM_{10} concentrations. Accordingly, no new data have been introduced since 1989 except for hourly PM_{10}

concentrations and the meteorological data associated with those high PM_{10} concentrations produced by vehicles on paved roads that are covered by sand and gravel spread for added traction. Hourly PM_{10} data have been available only since November 1992 and the increased information available from such data justified the addition to the data set.

Measurements Within the Nonattainment Area.

The measurement of 24-hour average PM_{10} concentrations in Spokane began in November 1985; hourly PM_{10} concentrations are available beginning in November 1992. At one time or another PM_{10} concentrations have been measured at nine locations in Spokane. Only the Crown Zellerbach site has maintained a nearly every-day sampling frequency for the period of record; other sites have operated at lesser frequencies or have operated for only short periods. Therefore much of the analysis has concentrated on the measurements made at the Crown Zellerbach site.

Background Measurements (Turnbull Slough).

Background particulate concentrations are those concentrations that would be measured if all sources included in the modelling inventory were eliminated. For the Spokane PM_{10} non-attainment area, the background sources are located sufficiently distant that the concentration gradient across the modelling domain will be very small. Therefore the background monitoring site needs only to be located where it is unaffected by either Spokane sources or any nearby sources. The monitoring site at Turnbull Slough is an excellent candidate.

Particulate matter has been monitored at Turnbull Slough since 1971. The Turnbull Slough location is well suited as a background monitor for Spokane as it is well removed from any urban sources and reasonably separated from the influence of local agricultural sources. The shift from monitoring TSP to PM_{10} did not occur at Turnbull Slough until 1992. The Turnbull Slough site maintained a one-in-six day monitoring schedule until 1993. Therefore background values of PM_{10} concentration that may be used for modelling Spokane for 1985 - 1989 must be derived from TSP measurements which generally do not align with the days of interest. Analysis shows that the average background particulate concentration varies with the time of year. The available data were used to compute the mean particulate concentration as a function of the day of year. The mean and standard deviation of the particulate concentration were constructed by using a sliding 30-day window and discarding data more than three standard deviations from the mean. This approach removed outliers such as those produced by Mount St. Helen's 1980 eruption and produced the relatively smooth curve shown in Figure K-1. This "climatological" mean represents the best estimate of background TSP concentration on those days when no measured value is available.

METEOROLOGICAL INFORMATION

1985 to 1989.

Meteorological data taken at both Spokane airports during the 1985 - 89 period were examined for use in modelling the days of interest. Data from Spokane International (Geiger Field) are available in magnetic form and are easily analyzed. However Geiger Field is located in the southwest corner of the domain on high ground 400 feet above the Spokane River valley. Data from Spokane Felts Field, which is located alongside the Spokane River east of the Central Business District are available in hard copy only and therefore require manual entry prior to analysis. Initial modelling showed that use of the data from Felts Field produced concentration fields that more closely agreed with observations.

The surface weather observations are a snapshot of the current weather and are best used to model long periods rather than the hour-to-hour detail. The very nature of these data guarantee that individual hours may not be representative of the mean meteorology for the hour. Standard surface observations especially suffer during times of low wind speed since speeds less than three mph are considered calm with no reported direction. As Table K-1 shows, many of the highest PM_{10} concentrations occur on days with six or more hours of reported calm conditions. Table K-1 also lists the duration of individual calms making up each modelling period. Durations greater than six hours may produce less accurate estimates of atmospheric motion by the algorithm in WYNDvalley. Although the WYNDvalley model does not require estimates of mixing depth; the ISC2 model used for point source modelling does. The mixing heights were obtained from the routine soundings taken at Geiger Field. No adjustment was made to the mixing heights to account for the height difference between Geiger Field and the base elevation of the point sources. A simple adjustment based on the elevation difference would virtually eliminate all mixing heights smaller than 150 meters. Daytime mixing heights in the range of 30 to 150 meters can be expected to occur in the valley and will be associated with some of the highest ground level impact from the point sources.

Wind run data for the days plotted are in Figures K-2 through K-74. Note that many of the days are dominated by a general northeasterly flow which will have significance for the WYNDvalley modelling as discussed later. High wind days stand out from those with generally light and variable winds. Many days are characterized by a disorganized wind run where the wind direction shows major changes throughout the day. One day, 9 December 1986, was eliminated from consideration; the wind was calm for the entire day and there were no data for the dispersion model to use.

1992 to 1993.

Better surface meteorological data were available for the 1992 - 1993 modelling period used to analyze the contribution of traction materials to the particulate concentration and evaluate the effects of control strategies. The Ecology-run monitoring site at Crown Zellerbach, where both continuous and reference method PM_{10} monitors are located, measures and reports the hourly mean wind speed and wind direction, standard deviation of the wind direction, and the temperature. Unfortunately the Crown Zellerbach site does not measure dew point or relative humidity and the dew point data from Felts Field were substituted in the computation of the vapor pressure used as a predictor of surface wetness. Occasionally the Felts Field dew point was reported as being higher than the Crown Zellerbach dry bulb temperature and the vapor pressure difference was set to zero for those hours. It is believed that the adjustment has negligible effect on the analysis since it will occur only under nearly saturated conditions when roads are likely to be wet.

Felts Field cloud cover was used in the point source modelling to compute atmospheric stability. At the time of analysis, no mixing height data were available for the 1992 - 1993 modelling period and a mixing height of 1000 meters was used for all point source modelling. Previous modelling had showed that plume behavior for all point sources was dominated by building wake effects. Since the distances of interest were less than a few thousand meters, the effect of mixing height is not significant.

SOURCE CATEGORIES

The Spokane PM_{10} emission inventory was divided into two categories, point and area. The point sources conveniently split into three geographically separated groups: Kaiser Mead, Kaiser Trentwood, and a cluster of small point sources located along the railroads east of the downtown area. The division allowed each group to be evaluated independently since the regions of appreciable contribution from each group do not overlap. In order to understand the importance of the different activities emitting PM_{10} in Spokane, area sources were divided into these nine classes: certified wood stoves, uncertified wood stoves, other residential heating, paved roads, unpaved roads, unpaved parking lots, open burning, windblown dust, and other area sources. These classes were chosen after considering potential or existing control strategies, perceived contribution to the PM_{10} concentrations, and spatial and temporal variability of emissions.

Point Sources.

In general point sources operate at levels lower than their maximum and often on reduced schedules. Therefore both hourly and daily actual emissions are less than their maximum potential to emit. To the extent possible the actual emissions were used in the model validation portion of this study. In some cases the actual emissions of a minor source could not be clearly defined and the maximum potential emissions were used. The maximum potential emissions were used to ascertain the impact on control strategies and future attainment status. Nearly all point sources are subject to building wake effects and building dimensions were used to compute those effects.

Area Sources.

The Spokane PM_{10} non-attainment area is roughly rectangular with an area of 599 square kilometers (Figure K-75). Model resolution and execution time and data availability considerations decreed that the area sources be defined with a one kilometer resolution. Consequently, the non-attainment area was divided along the integer kilometer UTM coordinates producing a checkerboard pattern of 599 cells. As described in more detail below, emissions from each area source class were estimated from available data for each cell. This description of the area sources means that the dispersion model will treat the emissions as being spatially uniform within each cell for each emission class. The non-attainment area is characterized by significant terrain elevation changes which may be expected to affect dispersion. Based on observation, a terrain height approximately 200 feet above the Central Business District was used to define significant terrain features. Those cells above 200 feet were excluded from the modelling, leaving 346 cells in the dispersion modelling domain.

In general, area sources have two types of variability: spatial and temporal. Both types were accounted for in the modelling done for this Attainment Plan.

Residential Heating Emissions. Emissions associated with residential heating, certified and uncertified wood combustion and other residential heating, were computed on the basis of households per square kilometer and survey results (BPA, 1991) were used to define the fraction of households using each type of heating unit. Figures K-76 through K-78 show the emissions from the residential heating sources. In certain areas of the city having a large fraction of multiple unit dwellings the fraction of wood burning units was decreased. BPA survey results were also used to define the general time-of-day usage for wood burning units (Figure K-79). All residential heating was also modified by using the standard 65F based heating degree day to estimate the heating requirements for each day. Previous analysis, conducted for the Yakima PM_{10} SIP showed that wood stove use was significantly different before 1989. Prior to 1989 surveys established that many wood stove users customarily filled their stoves with wood, which often was not properly seasoned, and reduced the air supply to the minimum required for combustion in an effort to extend the burn time. Following implementation of the state law allowing curtailment of wood stove use during certain high pollution periods and the education campaign associated with it, residential wood stove use changed to agree with current practices. Consequently, the emission factors for uncertified stoves changed from 40 grams PM_{10} per kilogram of wood burned in 1985 through 1988 downward to 15 grams per kilogram by 1989. Other residential heating emissions account for the use of coal, oil, and gas.

On-Road Sources. Transportation related emissions from paved and unpaved roads and unpaved parking lots are varied by time-of-day. This hourly variation was defined from traffic volumes measured during a two week period during April 1992 as part of the survey done for the Spokane CO Attainment Plan (Figure K-79). Other adjustments to emission rates are made to account for the effects of moisture and freezing conditions. In general, unpaved roads do not emit from after the first snow in autumn until approximately four weeks after the winter snows have melted or whenever significant rain falls. The adjustment of emissions from paved roads is somewhat more complex but may be summarized by "no emissions when wet or snow covered."

Paved Roads. The spatial distribution of emissions from paved roads is derived using the SRC transportation model for defining peak hour vehicle counts for each link in their model. The SRC model also provides the location of the endpoints of each link permitting an apportionment of traffic density and link length to each cell. The peak hour counts are converted to daily counts by using data from the CO traffic survey. Additional analysis of paved road emissions is based on the EPA Report "Street Sanding Emissions and Control Study, (PEDCO, 1989)." Tables in the report show "baseline" emissions from paved roads along with the corresponding measured silt loadings and daily traffic counts. To the degree of precision reported, the silt loading remains at a low and constant value (about 0.015g/m^2) for ADT greater than 6000, then rises at lower ADT. These measurements were used with traffic count data to establish a relationship between daily traffic and silt loading for Spokane. Figure K-80 shows the relationship between ADT (daily traffic count) and silt loading. The Spokane data taken in August of 1992 supports the same behavior except the low level is at 0.042. In reformulating the paved road emissions it has been assumed that the Spokane data shows the same break at 6000 and increases to the 1.21 value found on residential streets (ADT assumed to be 150). For analysis it is useful to break the variable portion of the curve into six nearly equi-spaced intervals corresponding to silt loadings of 1.21, 1.0, 0.5, 0.2 , 0.1, and 0.05.

The guidance (AP-42) for computing emissions from paved roads on which traction materials have been applied is imprecise: "observed a factor of four times (the emission factor of normal for paved roads)". Other studies support increases ranging from 100 to 500 percent. Model performance is improved in this study by factors that range from 2.5 to 5. In keeping with the available guidance a factor of four was applied to account for the presence of traction materials.

Unpaved Roads. Emissions from unpaved roads were computed from the SRC inventory of unpaved roads which listed the length of road and a code describing the road surface for every road in each cell. Table K-2 lists the road types and summarizes the associated emission factors. A survey of traffic counts and speeds (SRC, 1992) failed to show any correlation between speed and daily traffic count and, as shown in Figure K-81, established that a constant speed of 17.5 mph should be used for traffic on unpaved roads. Analysis also failed to establish any significant relationship between traffic counts on unpaved roads and number of households or the total paved road traffic in a cell, Figure K-82. The counter locations for the unpaved road traffic survey were picked to most accurately represent the daily traffic counts on the unpaved roads in a statistical sense. As a consequence some cells had more than one counter and others had none. The count data were statistically (Kriging) interpolated throughout the modelling domain producing a single traffic count to be used for all unpaved road segments within each cell. The coded surface information was used to assign an appropriate emission factor to each road segment. The emissions from unpaved parking lots were computed from estimates of the numbers of vehicles using the lot and the lot size. The same time-of-day adjustment was used for unpaved roads and for traffic on paved roads. There is no seasonal adjustment of traffic.

Open Burning. Open burning was accounted for by modelling it only in the areas where permitted and during the hours and on the days allowed by the local regulation. No open burning occurred on the days being considered.

Wind Erosion. Analysis of windblown dust is not addressed in the Spokane PM_{10} attainment plan.

Other Area Sources. Other area sources (planes, trains, etc) are assigned to the cell(s) where the emissions occur and have no time dependence.

Summary of Emissions.

Emission rates for each cell on specific hours depends not only on activity level within the cell but may also depend on the time of day, the heating value expressed in degree-days, an accounting for the effect of moisture on paved and unpaved roads, and the presence of traction materials on paved roads.

SUPPORTING STUDIES

Initial analysis and modelling showed that three major source categories would most likely be the dominant ones in the analysis of the Spokane PM_{10} non-attainment area: 1) Wood smoke from residential heating, 2) Resuspended dust from paved roads especially when covered by sand and gravel used for traction, and 3) Dust from unpaved roads. Several surveys and studies in the Spokane area have contributed data to this analysis.

In 1990 the Bonneville Power Administration, the State Energy Office, and the Department of Ecology commissioned a survey of wood stove use in Washington. The survey results were used to estimate the amount of wood used and the time of day when wood was burned.

In August 1992 DOE personnel measured silt loadings on several city streets in Spokane. These measurements were used with traffic count data to establish a relationship between daily traffic and silt loading for Spokane. Table K-3 shows the measured silt loadings. Several studies have measured PM_{10} concentrations in the vicinity of paved and unpaved roads.

Another study investigated the sources of particulate matter by using chemical fingerprints. Beginning in February 1991 and continuing for 13 months, daily sampling of PM_{10} was done at two locations, Crown Zellerbach and Country

Homes, with the specific purpose of providing samples for chemical speciation. At both sites particulate samples were taken concurrently on quartz and Teflon filters for 24-hour periods beginning at midnight. The objective of the study was to determine the contributors to the PM_{10} burden on those days when PM_{10} concentrations exceeded 120 $\mu g/m^3$.

The samples were analyzed to determine and discard those pairs which were inconsistent; that is those where the total PM_{10} concentrations calculated from quartz and Teflon filters differed by more than 30 percent. The highest acceptable sample was 136 $\mu g/m^3$ and the second highest was 104 $\mu g/m^3$. A comparison of the chemical signature using relative chemical abundances for the primary emission sources (wood smoke and crustal materials) from the "Receptor Model Source Composition Library" and "Pacific Northwest Source Profile Library" and modelling for the highest day is shown in Figure K-83. It can be seen that the species concentration computed using the model agrees with those concentrations measured by the laboratory analysis. The degree of agreement is roughly the same as seen between the predicted and observed PM_{10} concentrations for the model validation. It is uncertain whether the contributors to PM_{10} concentration at the 100 $\mu g/m^3$ level maintain the same relative contribution at the 200 $\mu g/m^3$ level and the reader is cautioned about drawing specific conclusions.

Additional analysis was done to assess the contribution of SO_2 emissions from the Kaiser Mead facility on the concentration of sulfates in Spokane. First, as Figure 84 shows, there is only a weak correlation between sulfate concentration and PM_{10} concentration. Next, since the Mead facility is a source of aluminum and fluoride as well as SO_2, strong correlations between sulfate and aluminum and sulfate and fluoride would be evidence that the same source was responsible. Figures 85 and 86 fail to establish the needed correlation. Since aluminum is a component of crustal material, the plot has been truncated at the 100 microgram level of aluminum to ignore several days on which blowing dust occurred. The lack of correlation with measured fluoride concentration could be in part due to the fact that most of the fluoride emissions are gaseous. The monitoring site at Country Homes is very much closer to the Mead facility than the Crown Zellerbach site, and it might be reasonable to expect that aluminum and fluoride concentrations would be higher. Figures 87 and 88 show that there is no difference in the fluoride concentrations and only an insignificant difference in aluminum concentrations. The most significant pattern to emerge from the analysis is the relationship to sulfate concentration to time of year. High sulfate concentrations are seen during the cooler parts of the year but never during the warmer months. As seen in Figure 89, the sulfate concentration abruptly falls after 10 May and rises equally fast at the end of September. The nitrate concentration has the same behavior, leading to the conclusion that the primary sources of these species are closely related to emissions associated with space heating. Therefore it may be concluded that emissions of SO_2 from the Kaiser Mead facility do not contribute significantly to the PM_{10} concentration in Spokane.

Additional chemical analysis was performed on filters exposed during the March 1993 case. Filters from the Crown Zellerbach and Nazarene (Country Homes) sites for the period 9 - 13 March 1993 were analyzed for crustal related compounds (iron and calcium) and combustion related compounds (elemental carbon and organic carbon). It should be recognized that soil or road dust may also contain up to ten percent organic carbon. As Figure K-90 shows, the concentrations of iron, calcium, and organic carbon are strongly positively correlated with PM_{10} concentration. The good correlation can only be explained by an increase in crustal material contribution as the concentration increases from 100 $\mu g/m^3$ to 270 $\mu g/m^3$. Elemental carbon fails to show any correlation. The lack of correlation of elemental carbon with concentration shows that the contribution from combustion sources remained relatively constant. It can be seen that two filters (Crown Zellerbach taken on the tenth and eleventh) have high values of elemental and organic carbon for their measured PM_{10} concentration. However these anomolously high values do not seem to affect the correlation of iron or calcium with PM_{10} concentration.

MODELS

Analysis of the conditions associated with PM_{10} concentrations in Spokane shows a high degree of association between high concentration and low wind speeds. In fact, as Table K-1 shows, many of the high days have more than six hours of reported calm winds. None of the available guideline models can be expected to perform well under such conditions. Most of the high days occur during winter when the mixing depth is expected to remain below the surrounding terrain; which also cries out for a different model. Accordingly, the model of choice was WYNDvalley, an Eulerian grid model which can cope with the existence of boundaries and low wind speeds. WYNDvalley is also well suited to model area sources but has limited utility in modelling the details of the impact from point sources. Therefore ISC2, the most recent version of ISCST (Short Term Industrial Source Complex) model, was used to model the point sources.

ISC2.

ISCST is a classical Gaussian dispersion model which is used to compute the impact of point source emissions on the ambient concentration. The ISCST model uses stack emission parameters to compute the rise of buoyant plumes, building dimensions to compute the wake and cavity effects of air flow past structures as it affects material emitted from sources, and hourly meteorological and astronomical data to compute the dispersion and advection of the emitted material. ISCST, like all Gaussian models, discards calculations when the wind speed is less than one meter per second. If more than one-quarter of the calculations used to compute the average concentration (i.e., more than six hours out of twenty four) are discarded, then the average concentration is flagged as being affected by calms and should not be used. Even so, studies have shown that ISCST does an adequate job of predicting the impacts if a sufficiently long period of record is used. Therefore the point sources in Spokane were modelled using every hour of five years of meteorological data.

WYNDvalley.

WYNDvalley is an Eulerian grid model and is able to accommodate several types of boundaries. WYNDvalley has been shown to be superior to Gaussian models in light and variable winds in regions with complex boundaries. The WYNDvalley modelling domain is divided into square cells. Each cell represents a square prism of air divided into as many as five layers and sources may be defined as emitting into any level. All cells have the same number of layers. Each cell layer may have an emission term and all emissions for a model execution may be varied by the time of day. Unlike Gaussian models which compute only one concentration field for each hour, WYNDvalley typically steps through time by making several time steps each hour. At any time step the wind field is uniform in speed and direction throughout the modelling domain. The boundaries of the modelling domain may be defined in one of four ways:

> **open** - where the flow of pollutant is unimpeded with mass flow outward and clean air inward according to the wind direction
>
> **barrier** - which does not allow any flow across the boundary although horizontal diffusion between cells along the boundary is increased to mimic the increased dispersion caused by divergence in the vicinity of the barrier
>
> **leaky** - where the flow of pollutant can cross the boundary but dispersion across the boundary is computed as if a cell on the outside of the boundary has a concentration equal to one-half the concentration of the adjacent cell on the inside. Advection of pollutant when the wind blows from the outside towards the inside is also computed using the same assumption.
>
> **hybrid** - is a combination of the barrier condition at the lowest model level and a leaky condition at all higher levels.

The interaction of barrier, leaky, and hybrid boundary conditions with the uniform, non-divergent wind field can produce an unrealistic accumulation of concentration at downwind boundaries. This behavior is characteristic of this type of model and, as discussed below requires that computed concentration in the two cells nearest the boundary be discounted.

Approximately midway through the modelling for this project a new version (3.11) of WYNDvalley was released which contained better algorithms for handling the diffusion computation. Some investigators believe that the new model produced significantly lower concentrations that could give misleading results when evaluating control strategies. Except for a single point, where the newer model seems to provide a better handling of a day with a very high number of reported calms, there does not seem to be any appreciable difference (see Figure K-91). Therefore all modelling of area sources reported here was done with version 3.11.

MODEL PERFORMANCE

Validation

Dispersion modelling was done with two objectives in mind: 1) to validate the overall model performance ensuring that the model output may be used with confidence to evaluate the control strategies and 2) to assess the effectiveness of each control strategy in the effort to attain the standard. The first objective is best met with as large a data set as possible. To that end all days beginning with November 1985 and continuing through 1989 when at least one of the PM_{10} monitors in Spokane recorded a level of 120 $\mu g/m^3$ or greater were identified. Seventy two days were thus identified; thirteen were associated with blowing dust and one could not be modelled because the wind speed remained calm for the entire period. The remaining 58 days were distributed throughout the months of November through March.

Of the six monitoring sites in the Spokane area, only one, the Crown Zellerbach site, maintained a nearly every day sampling rate. Consequently, there were more data taken at the Crown Zellerbach site than at all of the other sites combined. As can be seen in Figure K-92, the concentration measured at Crown Zellerbach is, with few exceptions, the highest of the Spokane monitoring sites on each day. Therefore most of the model validation compares the model predicted concentration for each day with the observed concentration for Crown Zellerbach (see Figure K-93). Only a brief analysis of model performance is done at the other monitoring sites.

Initial Analysis of Performance.

Initially, validation modelling was done without modifying the emission inventory for any effects of precipitation or other sources of moisture or for any effects, such as the presence of traction material, which might increase the emission rates. Model validation, expressed as the ratio of model predicted concentration to the observed concentration, was poor except for those days falling in the month of October. October in Spokane is typically dry and free from effects that would alter the basic PM_{10} emission rates from paved and unpaved roads. Accordingly the methodology described below was developed to account for the effects of moisture on susceptible emission factors. The effects of dry traction material and of moisture on paved road emissions were assessed by using the 1992 - 1993 data. Control measures for traction materials were evaluated using data from early March 1993 when PM_{10} concentrations soared.

Methodology Development

The goal of the methodology was to provide a way of predicting the surface conditions of paved roads using commonly available meteorological data. Knowledge of the surface condition (primarily wetness) permits the emission rate from paved roads to be adjusted. Basically, PM_{10} emissions are zero for each hour the pavement is wet. The methodology was developed using meteorological and real-time PM_{10} concentration data for the period beginning in November 1992 and extending through March 1993. Both the meteorological and the concentration data were taken at the Crown Zellerbach monitoring site providing hourly averages of the appropriate parameters. Snow depth on the ground was measured at the Spokane International Airport (Geiger Field). Dew point temperature and sky cover were measured at Spokane Felts Field. The initial modelling of the March 1993 test period as plotted in Figure K-94 shows that the model performance was unacceptable during the first five days, predicting concentrations four to ten times higher than observed, but improved during the last three days. There are strong indications that moisture played a part in suppressing the emissions from paved roads during the first five days. The following will explain the methodology developed to predict paved road surface conditions.

In order to quantify the affect of moisture from such diverse sources as snow and rain on the road surface, water from melting snow, high relative humidity, or the "freeze drying effect" at low temperatures, the entire record of continuous PM_{10} measurements beginning just before the accumulation of snow started on 17 November 1992 was compared with model runs which used meteorological data obtained at Crown Zellerbach. Model performance, the ratio of predicted to observed concentration, was computed for each hour and related to various meteorological parameters. The highway surface condition data, reported to Washington DOT from sensors on Sunset Hill were also used to help determine when road surfaces were wet or snow covered.

The winter of 1992 - 93 was snowier than normal in Spokane with snow depths exceeding ten inches for much of the winter. Consequently, a large amount of sand and gravel was used as traction aids and was on the road surface in March 1993. By starting the analysis in November before the snow started accumulating and continuing it through March, when the last of the snow had melted, a complete data base was assembled. The objective of the analysis was to use the available data in conjunction with the dispersion model to predict whether traffic on the road surface will produce PM_{10} particles. The predictor consists of a variable that is greater than zero when the paved roads do not emit and zero otherwise.

If adequate data were available to quantify the energy balance, (measurement of water vapor flux, heat flux both in the air and the ground, surface albedo, etc) then the roadway surface conditions could be calculated with little error. However, the data are not available and other parameters must be used in place of those required by the energy balance calculations. This simplified model uses counters to record the accumulation of liquid and solid precipitation. The value of these counters is decreased by the effects of temperature and humidity for each hour when certain conditions are met.

First, a set of counters was defined to keep track of the accumulation of liquid precipitation, solid precipitation, and snow accumulation on the ground. It has been observed that precipitation in Spokane is most often classified as light (.005 to .10 inch of liquid or melted precipitation per hour). Previous studies have shown for other parts of the country that the ratio of the median precipitation rate for moderate precipitation (.11 to .30 inches per hour) to that for light precipitation is four to one and the ratio for heavy precipitation (greater than .30 inches per hour) is 15:1. Therefore since both liquid and solid precipitation must be accounted for, the appropriate unit of accumulation (1, 4, or 15) was added to a counter for each hour when solid or liquid precipitation was reported. It was acknowledged that solid precipitation may accumulate without limit and snow removal would result in berms of snow alongside roads after some minimum amount of snow had fallen. As a simplifying assumption, liquid precipitation was not permitted to accumulate beyond a count of four to reflect runoff. It is obvious that this model does not differentiate rain falling on dry soil from rain on saturated or frozen soils or on snow covered ground.

The second part of the surface prediction model accounts for the removal of moisture, either liquid or solid, by evaporation, sublimation, or melting. Evaporation rate is directly proportional to the difference between the saturation vapor pressure and the ambient vapor pressure at the surface of the liquid. As an approximation, these two pressures were calculated using the dew point and dry bulb temperatures. The pressure difference in hPa was subtracted from the liquid counter for liquid precipitation. Snow melt caused by falling rain is modelled by subtracting a fraction of the liquid precipitation rate. Sublimation is handled by subtracting a fraction of the vapor pressure difference. When the accumulated snow counter exceeds 20 or the berm counter is greater than zero, each hour of reported snow fall also adds to the berm counter. Berm melt is accounted for by subtracting the number of degrees C the temperature is greater than 4 C from the berm counter, that is, an hour when the temperature is 8 C will subtract four. It was found that better behavior of the model could be achieved by including a modification which allowed the pavement to dry out at temperatures below -5 C. Improvement was also noted by assuming that condensation on paved surfaces occurred when the vapor pressure differences were small. The entire algorithm is diagramed in Figure K-95.

Detailed Analysis of the Methodology.

The objective use of the methodology, while improving the model performance, still did not fully account for certain days when the model predictions were more than thirty percent in error. At the urging of the EPA Region X staff a detailed analysis was done of those days and is summarized in Table K-4. As the following figures show, model performance becomes quite acceptable when the objective methodology is supplemented by reasonable subjective corrections. Model performance is almost entirely clustered between 0.5 and 2.0 which are the usually accepted limits and two-thirds are within thirty percent of the monitored value.

November 1985 was characterized by snow (11 inches on the ground for the last ten days) and extreme cold (average temperatures running between 20 and 40 degrees below normal). 23 November was the coldest with an average temperature of -10 F (75 heating degree days). It is entirely possible that the simple heating degree day dependence used to modulate wood stove emissions does not extend to such extreme conditions and will overestimate the emissions from wood stoves. It seems reasonable that wood stoves being used for heat will be operated at higher heat output and therefore more efficiently. The effect of the higher than average efficiency of operation is all the more important considering the usual mode of wood stove operation that was prevalent in 1985. 27 November had an average temperature of -1 F and was similar to 23 November.

By 13 December 1985 the precipitation had stopped, leaving an eight inch snow pack on the ground. The temperature remained well below normal (average temperatures of 10 to 20 degrees below normal). The objective scheme attempts to detect periods when paved roads dry out when temperatures are well below freezing (less than -5C) but it uses the difference between the ambient and saturation vapor pressures to screen against moist non-precipitating periods. A vapor pressure difference of 1 millibar seemed to work on the data set used to establish the scheme but will fail at extremely cold temperatures where the saturation vapor pressure is less than 1 mb. The subjective tweaking to allow the paved roads to emit and multiplying the concentrations by four to reflect the effect of traction materials brings the predicted concentrations more in line with those observed for the period 13 - 17 December.

The model performance figure (Cp/Co) at Crown Zellerbach is too high for 14 and 26 January 1986 and so the performance at the other monitoring sites was assessed. The ratio of the average predicted to average observed concentration indicates that the model may be satisfactorily predicting the overall concentration field but failing to provide the details. The tendency seems to be to over-predict the concentrations in the southern portion of the domain (Auto Glass to University City) and under-predict the concentrations at Country Homes (opposite the behavior of 27 Nov 1985 where the model over-predicted the concentration at Country Homes).

Model performance can be improved by accounting for the effect of traction materials during the period 27 February 1986 through 3 March. The objective predictive scheme seems to correctly predict mostly dry surfaces for the three days and multiplying the predicted contribution from paved road dust by four to account for traction materials produces satisfactory agreement with the observations.

The predicted concentrations for 21 January 1987 are uniformly high, averaging nearly twice the observed concentrations. There are three inches of snow on the ground and the temperature averaged 14 F. Fog was reported and the average dew point was 12 F. Although the high temperature only reached 26 F, the day was clear (97 percent of possible sunshine), and some melting probably occurred. The objective scheme did not turn off the emissions from paved roads during the day and, combined with the apparent tendency to over-estimate emissions from wood stoves during very cold periods, may have produced the over-estimate of the concentration.

On 08 February 1987 the predicted concentration at Crown Zellerbach was twice the observed, the observed at Country Homes was twice the predicted, and the predicted concentration at University City and Auto Glass was about 30 percent high. The snow pack had melted by 03 February and the last precipitation also occurred on the third. The average temperature was 39 F and the winds averaged approximately 7 miles per hour. There is nothing to suggest that the model would have difficulty or to lead one to believe that the methodology should not accurately predict the times that paved roads would emit. The method predicted that the roads were wet for seven hours. The ratio of the average concentrations, predicted to observed, for all stations is 1.11 which, as discussed for 14 and 26 January 1986 seems to indicate that the model accurately predicts the average dispersion but not the individual details.

The situation on 23 February 1987 is quite different. The average wind speed for the day was 19 miles per hour from the northeast. With such a high wind, it should not be surprising that the model will predict low concentrations. There is no background (or even other Spokane) monitoring data and one cannot be sure that the Crown Zellerbach site represents the concentration at other sites. It seems likely that the high observed concentration may be due to a local source (perhaps even on the roof where the monitor is located) that is not otherwise documented or was only present for a short time.

In general the model performs best during October when the effects of moisture are minimized and the AP-42 emission factors for both paved and unpaved roads are most representative. October 1987 (Figure K-96) started out warmer than normal (average temperatures five to ten degrees F above normal) then cooled to below normal (six degrees below normal by mid-month). Only 0.03 inches of precipitation fell and, although average wind speeds generally remained below 7 mph (the resultant wind speed was 1.1 mph for the month), every day had peak gusts greater than 12 mph and many days had fastest miles with speeds greater than 10 mph. As seen in Figure K-97 the days with the highest monitored concentration are well predicted by the set of days with low resultant wind speed. The climatologically averaged TSP concentration at Cheney slowly decreases from 55 at the beginning of the month to the low thirties by the end. However, the measured TSP concentration at Cheney starts close to the long-term average at the beginning of the month but the 98 measured on the 24th and the 96 on the 30th are more than 60 above the long-term average. The days of concern are well defined by days with low resultant wind speeds which is consistent with poor dispersion as the cause of the high PM_{10} concentrations. The model underprediction on the 22nd and the 27th may be caused by using the climatological average (43 and 38 $\mu g/m^3$ respectively) when it could be argued that the available data show that the background concentration was likely above 90.

The period 23 - 27 February 1988 benefits from multiplying the paved road emission factors by four to account for the effects of traction materials except for the 27th. However, if the other monitoring sites are included in the analysis, the domain-wide average performance is only 0.84. There doesn't seem to be an quantifiable explanation for the anomalous behavior at Crown Zellerbach, possible explanations might be that the street sweeping had already cleaned up the traction materials and that the detailed wind flow is not accurately represented by the winds at Felts Field.

The period 6 - 9 February 1989 is one of the first periods where wood stove curtailment was a factor. As such the analysis is complicated and several plausible solutions exist which improve model performance. All four days were colder than normal (average temperatures were in the range of 14 to 22 F). Although a trace of precipitation was recorded on the 7th, all four days had more than 95 percent of possible sunshine and the snow on the ground remained at a trace during the period. It seems possible that, with the high temperature of 33 and full sun on the 9th, snow on the ground or in berms along the streets melted and suppressed the emissions.

As shown in Figure K-93 the model performance is generally satisfactory when the failings of the methodology are accounted for.

Analysis of Bias.

There are a number of assumptions that have gone into the modelling analysis. Errors in making these assumptions may adversely affect the decisions made about the causes of high PM_{10} concentrations and the assessment of the proposed control strategies. This section will examine the performance of the model, after making the emission factor changes discussed in the preceding section. There are a number of sources of error which will affect model performance. In this analysis the expected sources of error are related to uncertainties in: 1) the background concentration, 2) ambient temperature, 3) wind speed, 4) some moisture related parameter (perhaps snow depth), and other factors.

Figure K-98, model performance as a function of background concentration, shows that the background concentration used does not seem to systematically affect the model performance. As Figure K-99 shows, there is no significant bias in model performance with respect to the day of year, although the scatter is increased for those times of year when the effect of moisture is expected to be important.

In Figure K-100 it can be seen that there seems to be a general tendency for the model to overpredict at lower temperatures and underpredict at temperatures above 40F. The overprediction at the lowest temperatures may reflect the expected reduction of wood stove emission factors when the wood stoves are run at high heat output. It may also be likely that the factor for wood stove use does not follow the classical heating degree-day factor commonly used to predict other space heating needs.

Model performance as a function of wind speed, see Figure K-97, shows a definite tendency towards underprediction at wind speeds greater than five knots. The WYNDvalley model is recommended for use as a substitute for the standard

Gaussian dispersion models for wind speeds less than five knots. For speeds less than five knots, the pattern is very nearly centered on model performance equal to one and on two-thirds of the days the model predicted concentrations are within thirty percent of the observed concentration.

Model performance as a function of the observed concentration is a very important indicator of model validity. Figure K-101 shows an apparent bias; the model seems to over predict at lower concentrations and under predict at the highest. First, considering the large overprediction at low measured concentrations, it should be recalled that the data set for model validation consisted of those days when at least one of the Spokane PM_{10} monitoring sites measured a PM_{10} concentration of 120 $\mu g/m^3$ or greater. Therefore, although the Crown Zellerbach monitor measured PM_{10} concentrations which were in the 50 to 70 range, other site(s) recorded higher values. Several explanations may be advanced, including: 1) the wind speeds and directions measured at Felts Field were not representative of the air motions affecting the site, 2) the concentrations measured at the Crown Zellerbach site were not representative of the concentrations in Spokane, and 3) there were undetected errors in the measurements (these were, after all, measurements made early in the PM_{10} monitoring program before all procedures had been worked out.) At the other end of the concentration scale is a potentially more important bias. The model underpredicts the very highest, non-windblown dust measurement by forty percent in spite of efforts to increase the emissions on the day.

Figures K-102, K-103, and K-104 show model performance at the Auto Glass, Country Homes, and University City monitoring sites, respectively. The overprediction at the Auto Glass location reflects the proximity of that site to the southwest boundary where the model is expected to overpredict. The model in predicting concentrations at the Country Homes site shows a wide scatter and except for the two highest observed concentrations remains within a factor of two. Unlike the behavior at the Crown Zellerbach site, the model overpredicts the concentration for high days. The sample size for the model performance at University City is too small to be significant but the indications are that the model performs well when the observed concentration exceeds 100 ug/m^3.

The objective approach used to account for the effects of moisture in all its forms on paved road emission factors could easily be an important source of bias. However, as shown in Figure K-105, there is no apparent bias as a function of the reported snow cover. Most of the days when model performance deviated outside the plus or minus thirty percent range occurred on days with no snow cover.

The model performance evaluation discussed so far has been looking at model performance as a function of physical variables which either are directly input to the model or affect one or more of the emission factors for the classes of sources modelled. It is also useful to compare model performance as a function of the amount of emissions from those source classes that are modified by temperature or moisture. However, to do so would require that all of the filters for the days included in the model analysis be sent to the laboratory for chemical speciation.

Since the chemical data are missing it becomes necessary to use the modelled source class contribution as an estimate. Figures K-106 and K-107 show the model performance as a function of the modelled wood smoke and road dust contribution respectively. In Figure K-106 the wood smoke contribution includes both certified and uncertified devices. The road dust contribution in Figure K-107 includes both paved and unpaved roads, although for most of the days modelled the unpaved roads were either muddy, frozen, or snow covered and did not emit.

One last model performance evaluation attempts to determine whether there is any bias in the ISC modeling of the point sources. Again since the chemical speciation data are not available, the evaluation is performed by using the modeled contribution of the point sources. The model performance, which is the ratio of the model predicted concentration to the observed concentration is plotted as a function of the predicted point source contribution in Figure 108. It can be seen that for predicted point source contributions greater than five micrograms per cubic meter there is no systematic bias.

Before discussing the next set of figures which show concentration isopleths on maps of Spokane, we should recall certain aspects of models such as WYNDvalley. WYNDvalley belongs to a class of models which simulate more physical processes than the classical Gaussian models but do not contain the complexity of full three dimensional flow models. WYNDvalley is able to account in a realistic way the effects of boundaries caused by high terrain, it accurately models the dispersion of material emitted in one layer of air into adjacent layers, and it makes use of atmospheric statistics to determine dispersion parameters. It lacks the ability found in the more complex models to allow different wind speeds and wind directions to exist in the modelling domain at the same time. That is, if the wind at a particular time step is northeast at two knots, then that wind speed and wind direction is used at every point in the modelling domain. Often that requirement will not cause a problem; however, if there is a barrier along the southwest corner of the domain, then the air is everywhere approaching the barrier and there is no turning or divergence of the approaching flow as would actually be seen. WYNDvalley attempts to reduce the effect by increasing the diffusion in the direction perpendicular to the flow, spreading out the concentration (essentially mimicking the divergence that occurs.) However a persistent flow approaching a sufficiently large barrier will still cause an unrealistic piling up of concentration in the vicinity of the barrier. Even the most sophisticated flow models have boundary effects that must be interpreted in special ways. A rule of thumb is to ignore calculated values within the nearest two cells of a barrier. Many models have built-in buffer zones that may be several cells deep which will not be reported or printed out. The more sophisticated models will often have variably sized cells which are used to mitigate the effects of the boundary. WYNDvalley does not incorporate such built-in buffer zones in its handling of the boundaries and so the proper handling of the boundaries is left to the user. While the Spokane modelling output presented in this plan shows values for all cells, values within the two nearest cells of a barrier are ignored for purposes of interpretation.

CONTROL STRATEGY EVALUATION

Evaluation of the proposed control strategies was done by rerunning the WyndValley model with the reduced emission rates appropriate for each strategy. As has been shown elsewhere, the three control strategies affect three different area source classes: residential wood combustion, unpaved roads, and paved roads (as augmented by traction materials.) In general, each of these classes has its highest emission rate at different times of year and in somewhat different regions within the modeling domain. As such the evauation of the control strategies may be discussed for each strategy alone with only minimum confusion from other contributing source classes. The control strategy evaluation also provides the vehicle to examine in detail the interaction of the area sources and the background values with the emissions from the point sources.

The following set of figures are based on the second highest total modelled concentration for each cell in the modelling domain. For each cell, once the second highest day has been identified, the modelled contribution of each source classification is looked up and contours are drawn for each contributing source class. The use of the second highest concentration is based on the following:

1) Monitoring data from the Crown Zellerbach site is available for nearly every day beginning in November 1985 and continuing to the present.
2) As Figure K-92 shows the monitored concentration at the Crown Zellerbach site is generally the highest in the modelling domain.
3) All days in the four-plus year period when at least one of the Spokane monitoring sites measured a concentration of 120 $\mu g/m^3$ or greater were included in the data set.
4) The National Ambient Air Quality Standard for PM_{10} essentially allows one excursion above the standard per year without penalty.

In most of the figures the boundary effect is strongly evident in the southwest corner and somewhat evident along part of the southern boundary of the modelling domain. Therefore only cells located more than two in from the boundary are used for the evaluation of attainment. The first figure, K-109, shows the total impact for all source classes without any controls and represents the baseline concentrations for Spokane. Generally the concentrations at the monitoring sites are within the range of values that have been measured but the modelling shows that some of the highest concentrations occur between the Country Homes and Auto Glass monitoring sites. The location of the maximum is dominated by wood smoke contributions and in fact may not be quite as large as modelled. The area has gentle terrain gradients which should serve to disperse the pollutants more than can be modelled by the WYNDvalley model. In any case, as shown by Figure K-110, the current curtailment strategy for wood stoves in Spokane provides adequate control.

The unpaved roads are the next source class to be addressed. Given the mix of significant source classes in Spokane, the contribution from any one of them probably should not be more than one-third of the 24-hour NAAQS of 150 $\mu g/m^3$. It is evident that the contribution from unpaved roads exceeds that guideline in certain parts of the modelling domain. Referring to Figure K-111, the map of unpaved road emissions, it can be seen that there are a few spots where the emission flux exceeds 1.0 g/(s-km^2) and that these spots seem to be associated with the cells highly impacted by unpaved road emissions. The control strategy targets those areas, and when combined with the other strategies (as shown in Figure K-112), no concentration exceeds the NAAQS.

PM_{10} emissions from paved roads with traction materials on them are another important source. The analysis shifts from the 1985 - 1989 data to the March 1993 set. Figure K-113 shows the predicted concentration with no source classes controlled. It can be seen that there are cells near the southern boundary (but outside the buffer area) that are predicted to have concentrations greater than the 24-hour standard. As the first cut, the same sources were modelled except that the traction material emissions were controlled to 70 percent by the strategies discussed elsewhere. Figure K-114 shows that the resulting concentration field almost shows attainment everywhere. Since wood stove use would also be curtailed whenever monitored concentrations climbed above 105 $\mu g/m^3$, the effect of wood stove curtailment was added to traction material emission controls to produce the concentration pattern shown in Figure K-115.

Although the basic resolution used in the modelling is one kilometer, which is appropriate for the area sources, the higher concentration gradients from the point sources within the modelling domain require closer scrutiny. This closer look was achieved by modelling the point sources with a dense array of receptors and adding the appropriate background and the highest WyndValley modelled concentration in the cell containing the receptors. The highest WYNDValley modelled concentrations in the vicinity of the Kaiser Mead and Kaiser Trentwood facilities are 35 and 38 ug/m^3 respectively. As Figures K-116 and K-117 show, the two Kaiser sources show no values greater than the 24-hour NAAQS. Evaluation of the region about the relatively smaller sources where the highest WYNDValley predicted concentration is 100 ug/m^3, is shown in Figure K-118 to be less than the NAAQS.

Figure K-1
AVERAGE TSP MEASURED AT TURNBULL SLOUGH, 1971 -1991

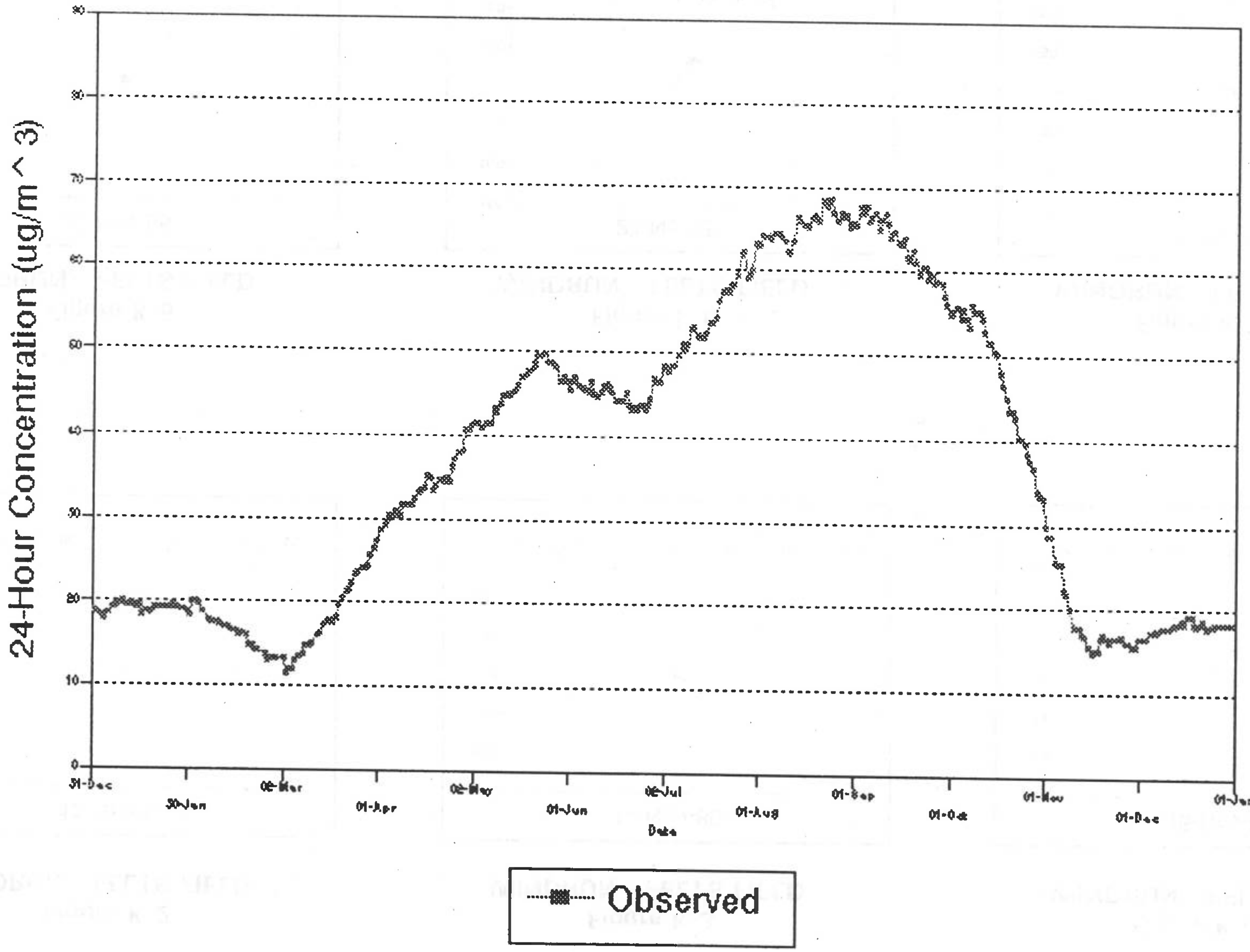


Figure K-2
WINDRUN - FELTS FIELD

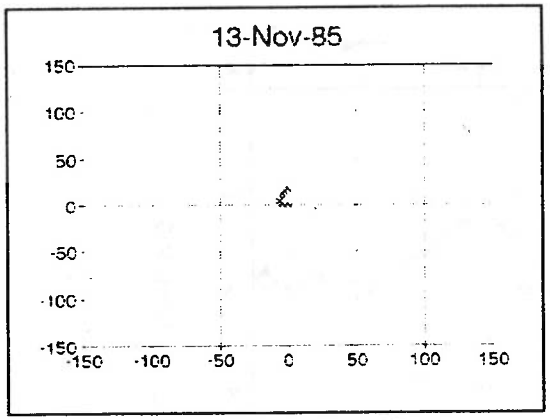


Figure K-3
WINDRUN - FELTS FIELD

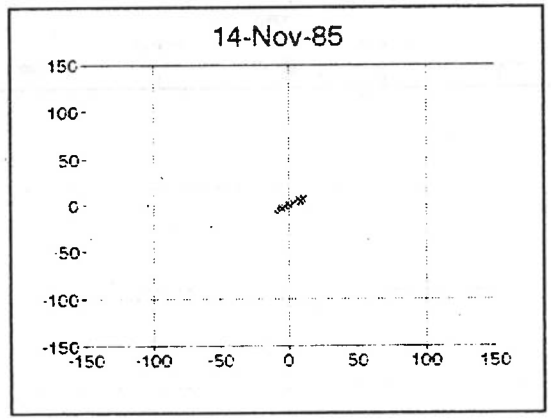


Figure K-4
WINDRUN - FELTS FIELD

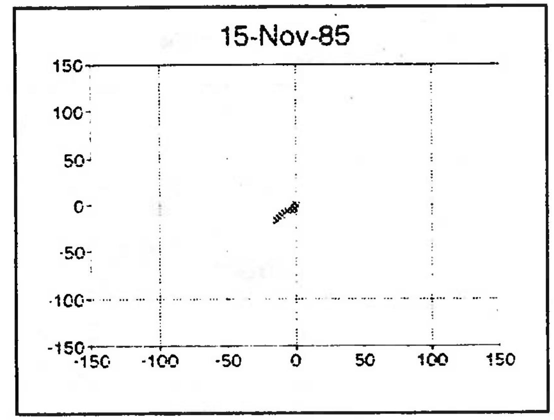


Figure K-5
WINDRUN - FELTS FIELD

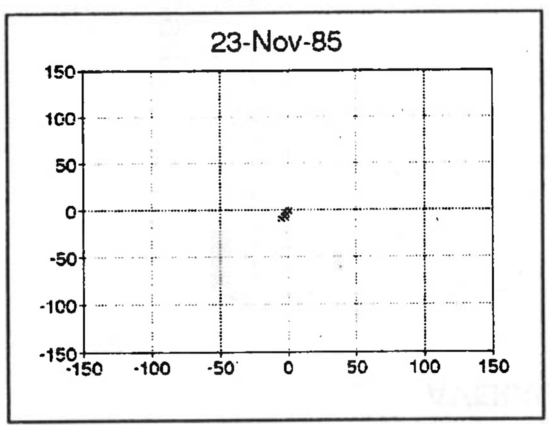


Figure K-6
WINDRUN - FELTS FIELD

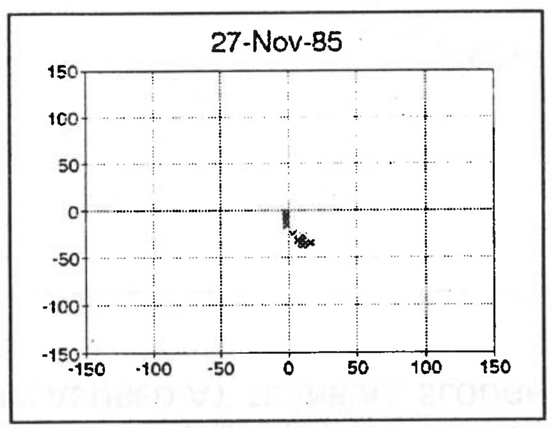


Figure K-7
WINDRUN - FELTS FIELD

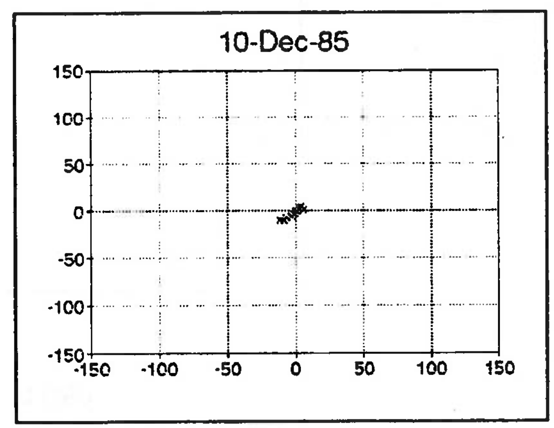


Figure K-8
WINDRUN - FELTS FIELD

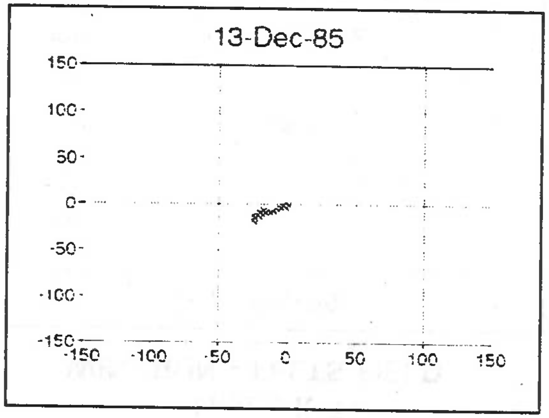


Figure K-9
WINDRUN - FELTS FIELD

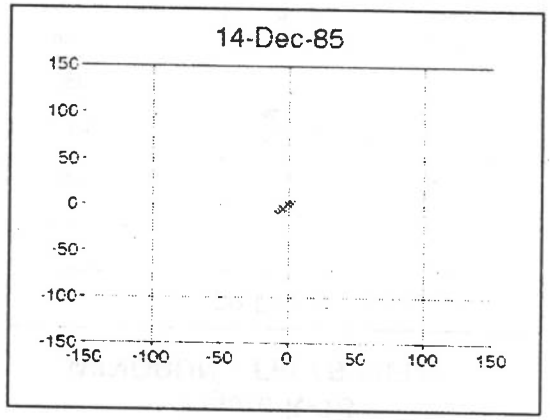


Figure K-10
WINDRUN - FELTS FIELD

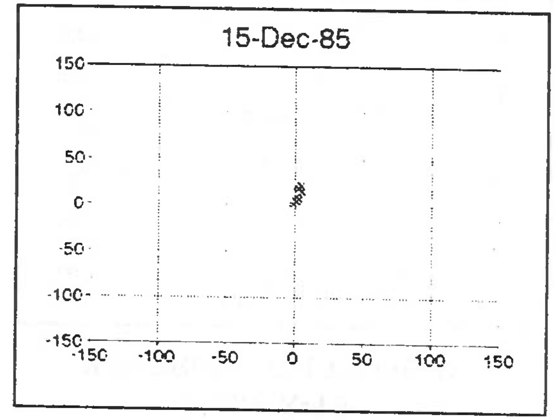


Figure K-11
WINDRUN - FELTS FIELD

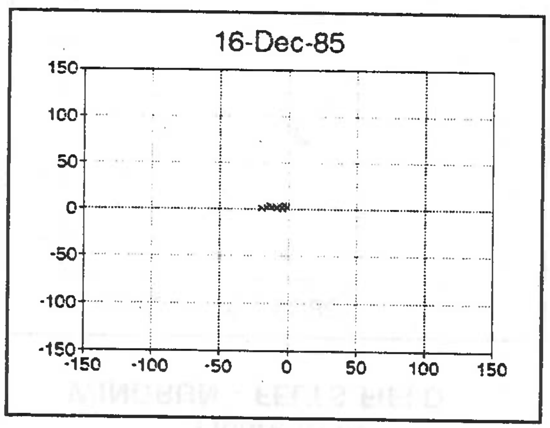


Figure K-12
WINDRUN - FELTS FIELD

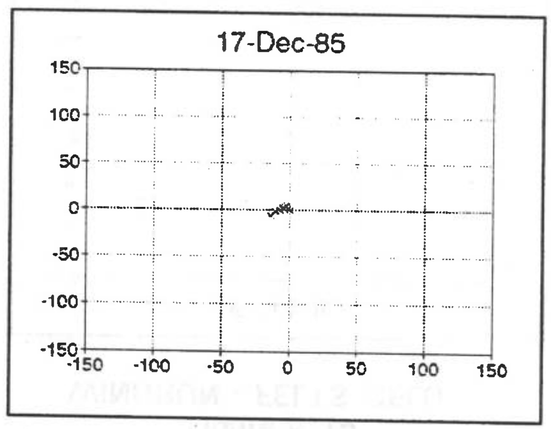


Figure K-13
WINDRUN - FELTS FIELD

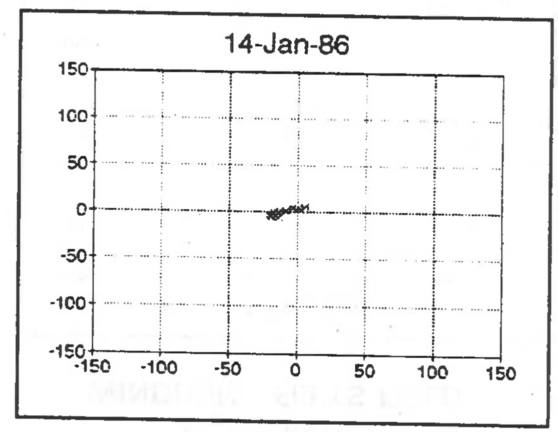


Figure K-14
WINDRUN - FELTS FIELD

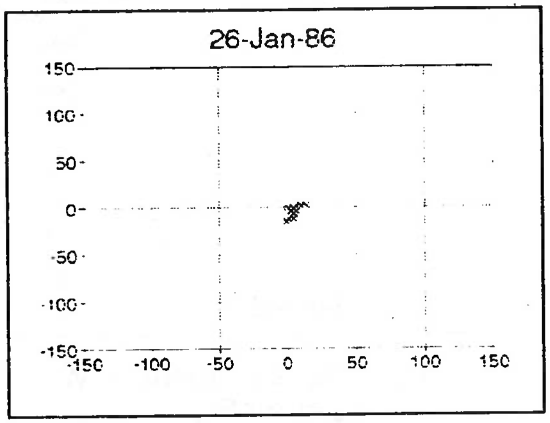


Figure K-15
WINDRUN - FELTS FIELD

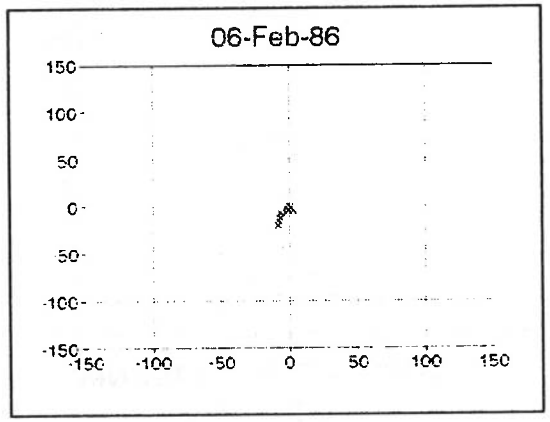


Figure K-16
WINDRUN - FELTS FIELD

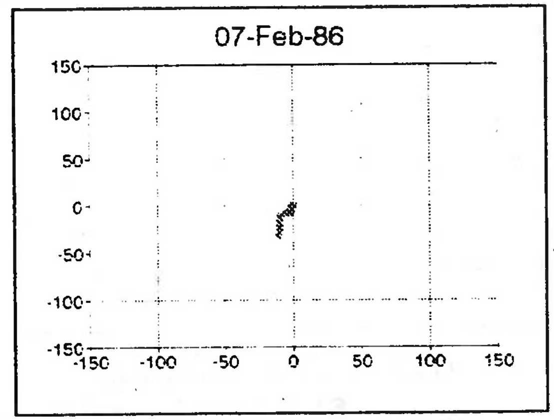


Figure K-17
WINDRUN - FELTS FIELD

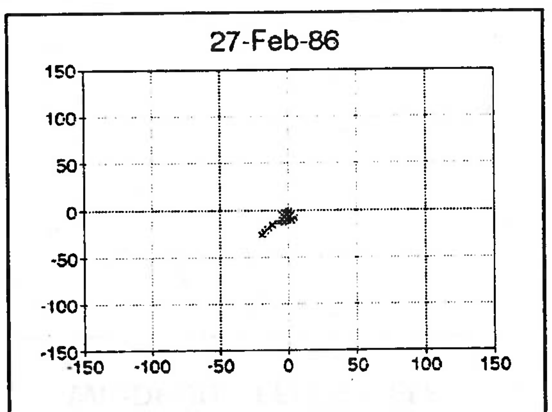


Figure K-18
WINDRUN - FELTS FIELD

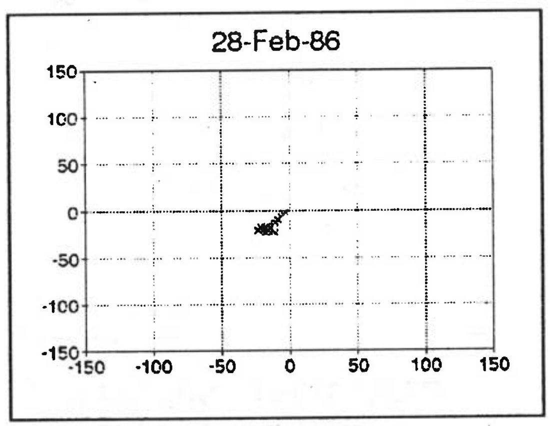


Figure K-19
WINDRUN - FELTS FIELD

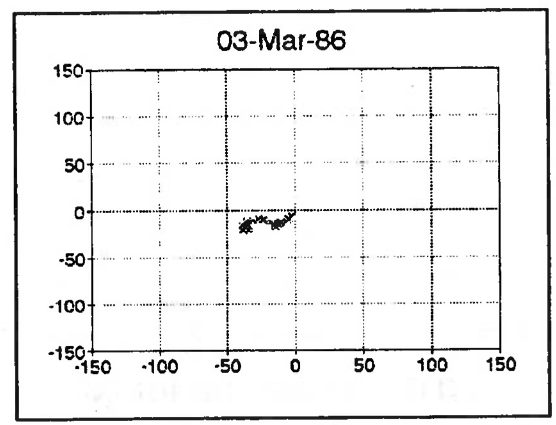


Figure K-20
WINDRUN - FELTS FIELD

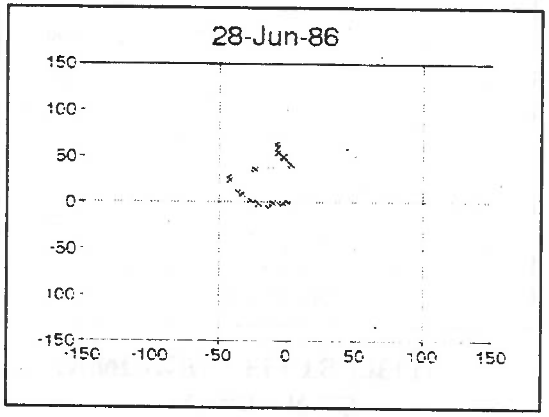


Figure K-21
WINDRUN - FELTS FIELD

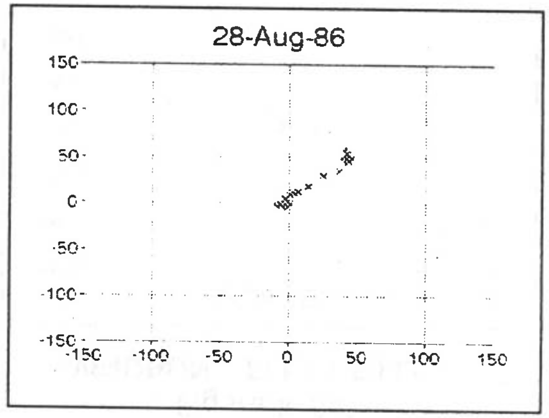


Figure K-22
WINDRUN - FELTS FIELD

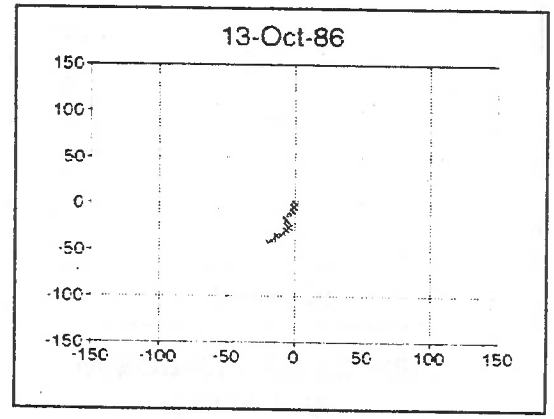


Figure K-23
WINDRUN - FELTS FIELD

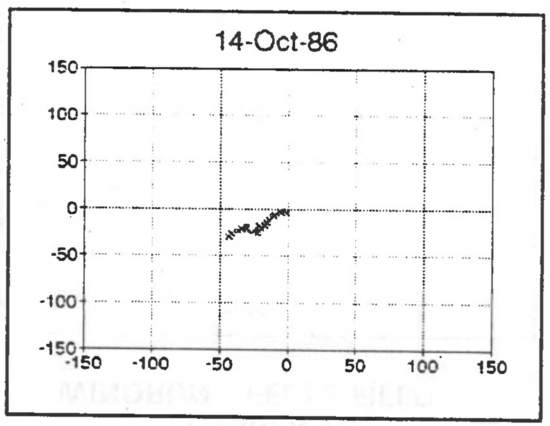


Figure K-24
WINDRUN - FELTS FIELD

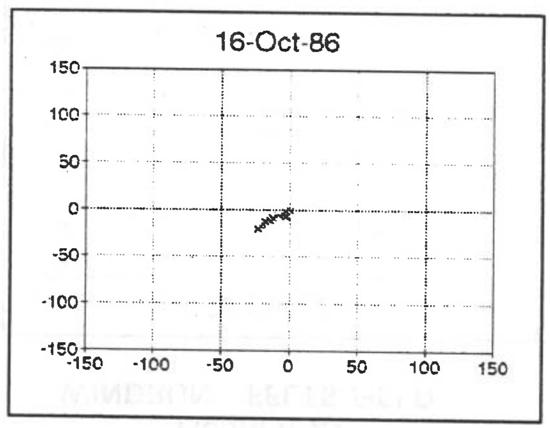


Figure K-25
WINDRUN - FELTS FIELD

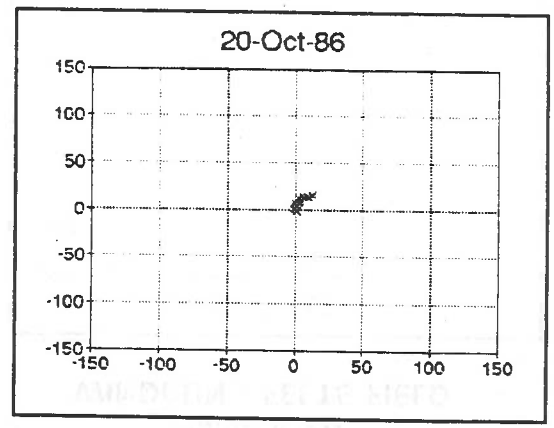


Figure K-26
WINDRUN - FELTS FIELD

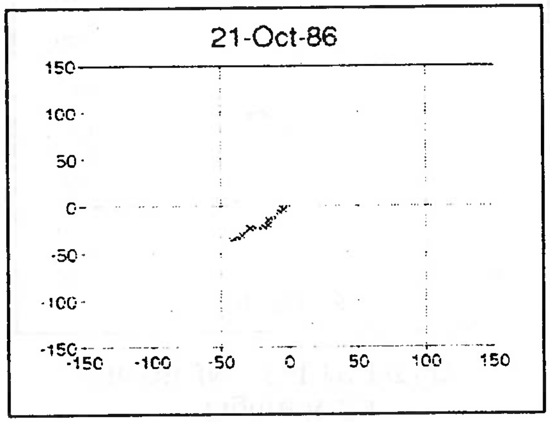


Figure K-27
WINDRUN - FELTS FIELD

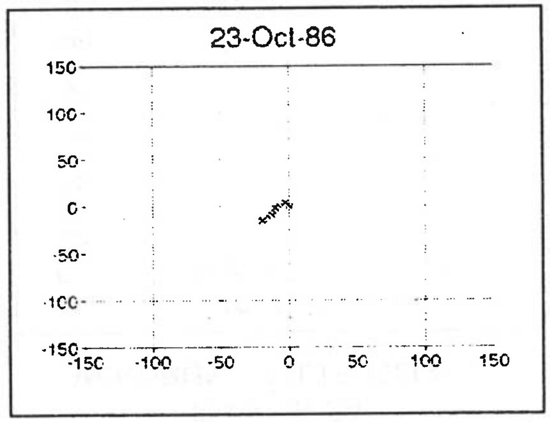


Figure K-28
WINDRUN - FELTS FIELD

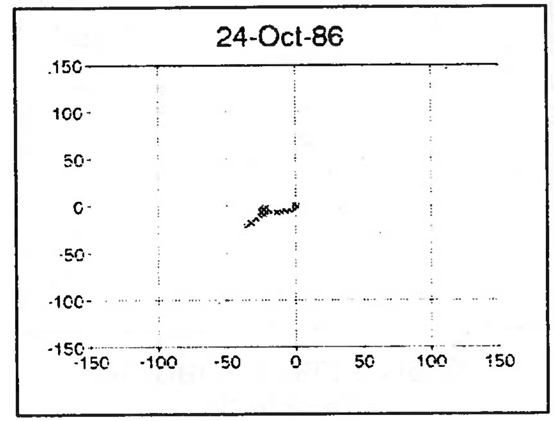


Figure K-29
WINDRUN - FELTS FIELD

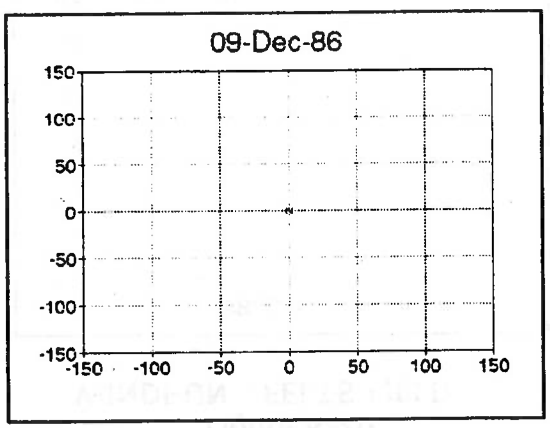


Figure K-30
WINDRUN - FELTS FIELD

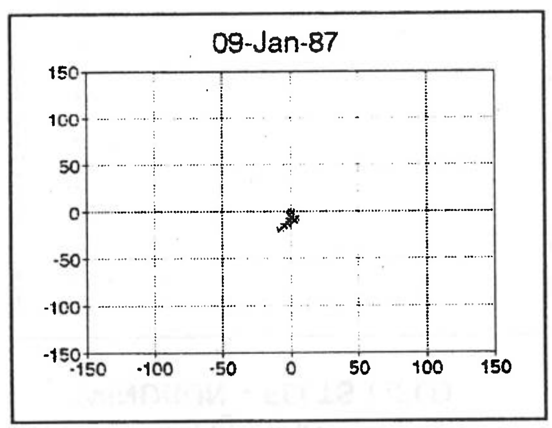


Figure K-31
WINDRUN - FELTS FIELD

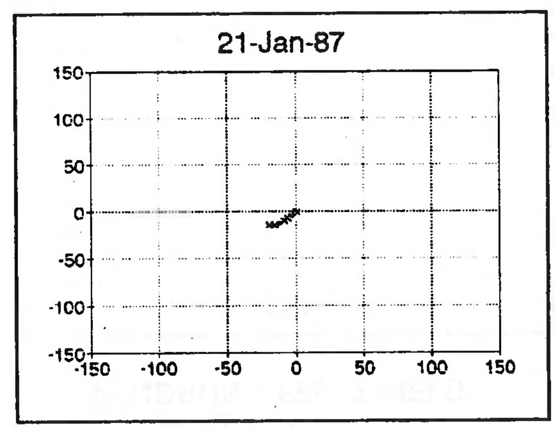


Figure K-32
WINDRUN - FELTS FIELD

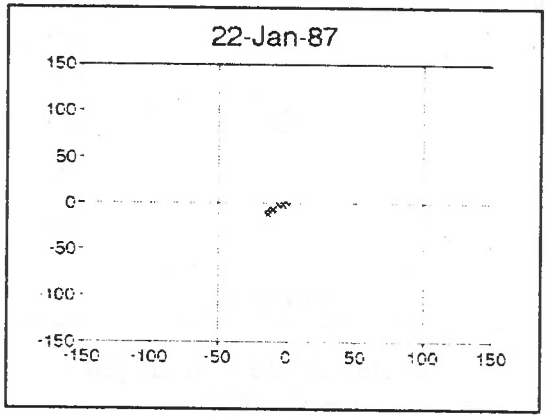


Figure K-33
WINDRUN - FELTS FIELD

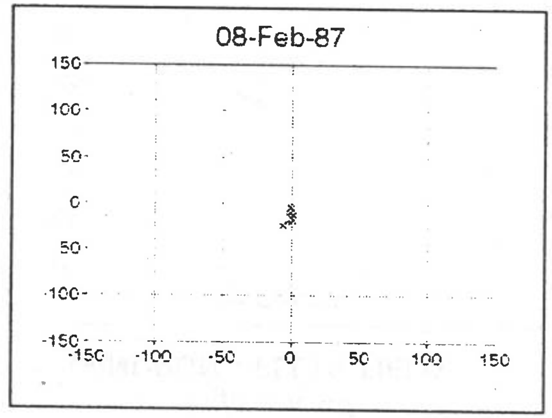


Figure K-34
WINDRUN - FELTS FIELD

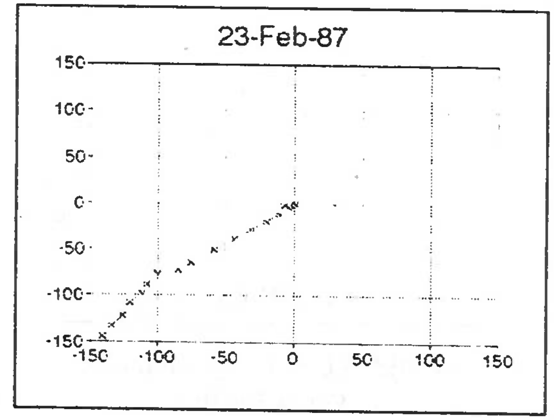


Figure K-35
WINDRUN - FELTS FIELD

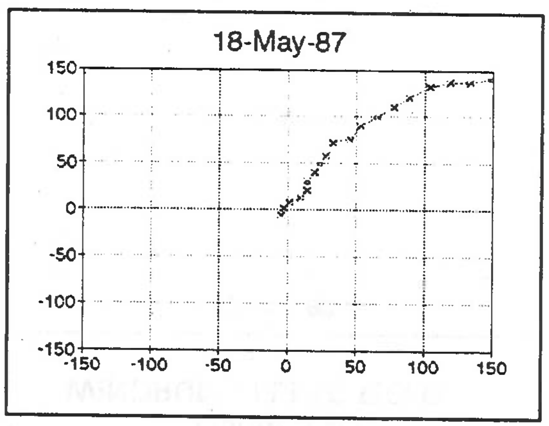


Figure K-36
WINDRUN - FELTS FIELD

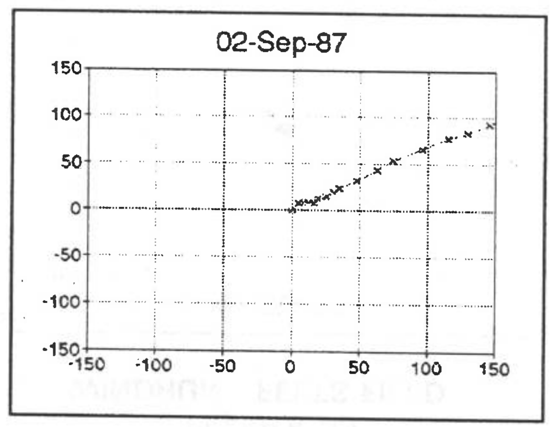


Figure K-37
WINDRUN - FELTS FIELD

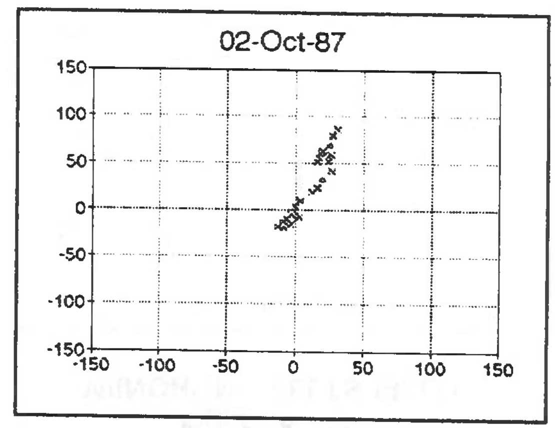


Figure K-38
WINDRUN - FELTS FIELD

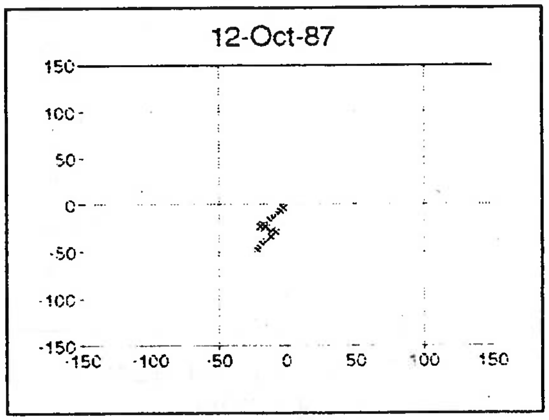


Figure K-39
WINDRUN - FELTS FIELD

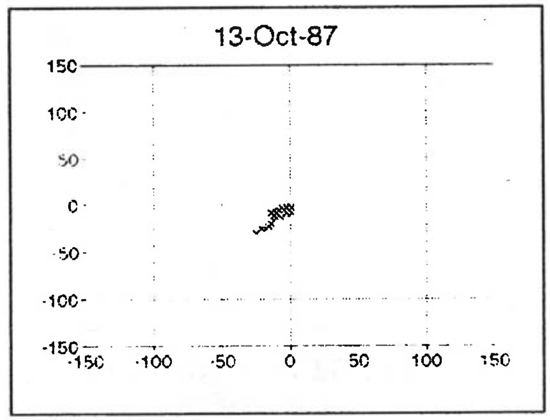


Figure K-40
WINDRUN - FELTS FIELD

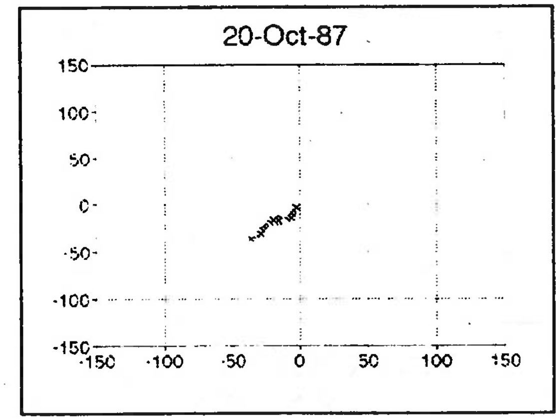


Figure K-41
WINDRUN - FELTS FIELD

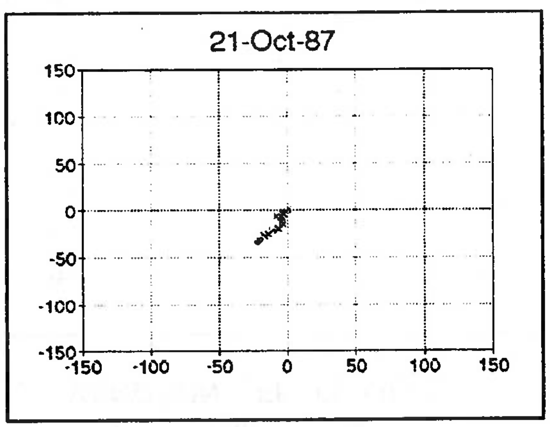


Figure K-42
WINDRUN - FELTS FIELD

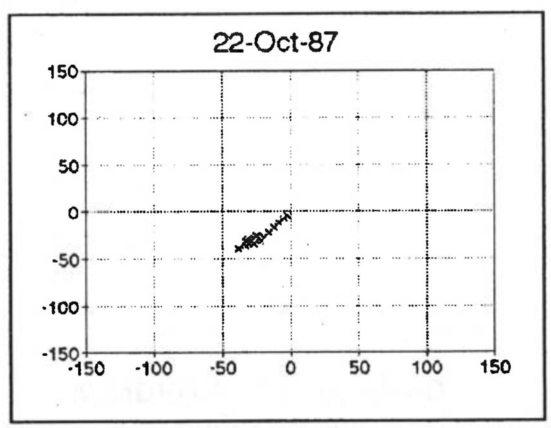


Figure K-43
WINDRUN - FELTS FIELD

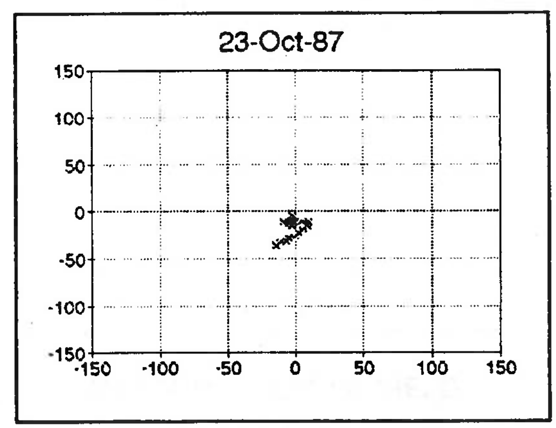


Figure K-44
WINDRUN - FELTS FIELD

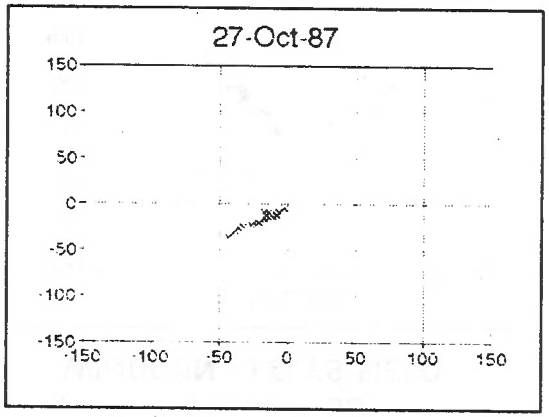


Figure K-45
WINDRUN - FELTS FIELD

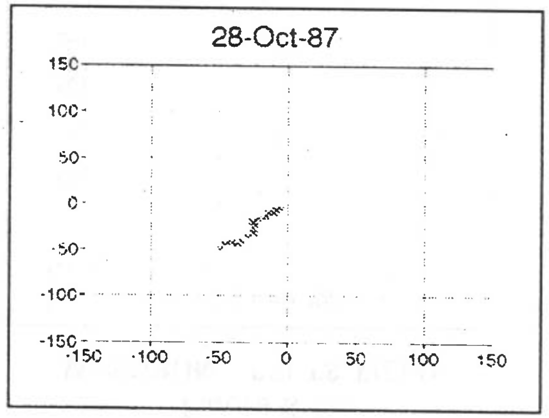


Figure K-46
WINDRUN - FELTS FIELD

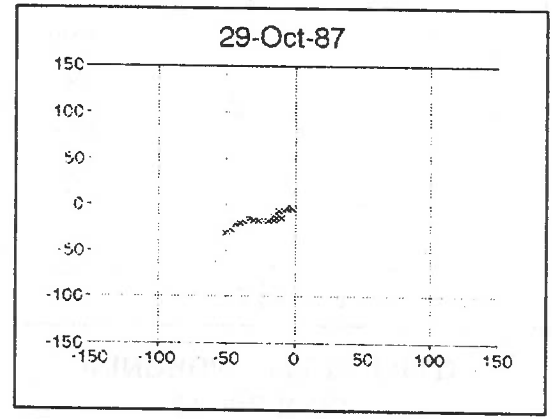


Figure K-47
WINDRUN - FELTS FIELD

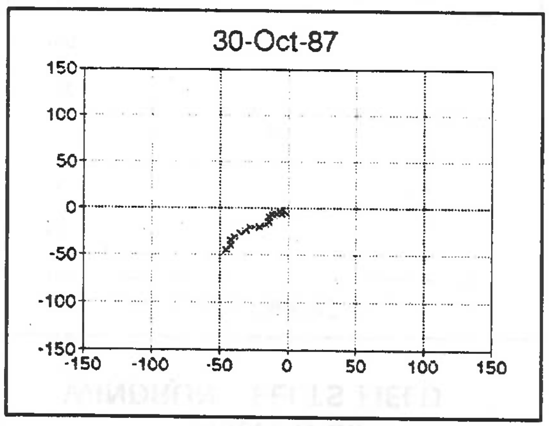


Figure K-48
WINDRUN - FELTS FIELD

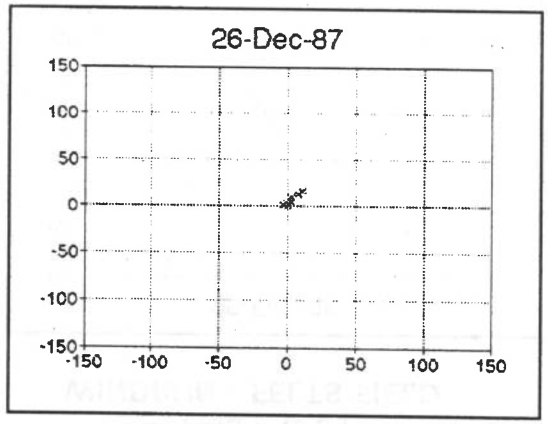


Figure K-49
WINDRUN - FELTS FIELD

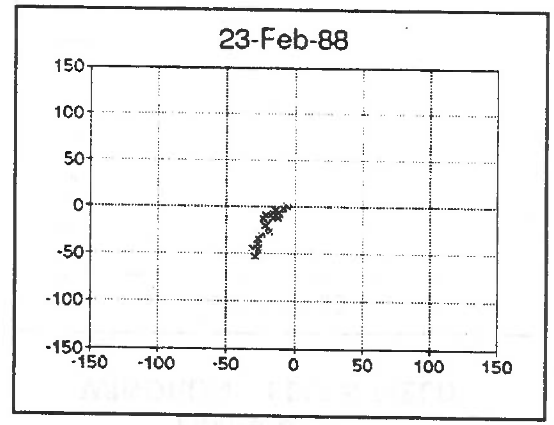


Figure K-50
WINDRUN - FELTS FIELD

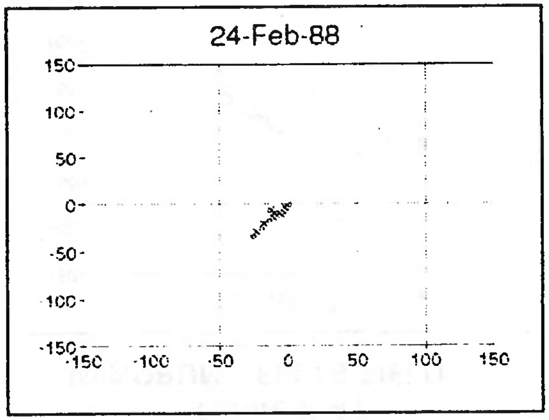


Figure K-51
WINDRUN - FELTS FIELD

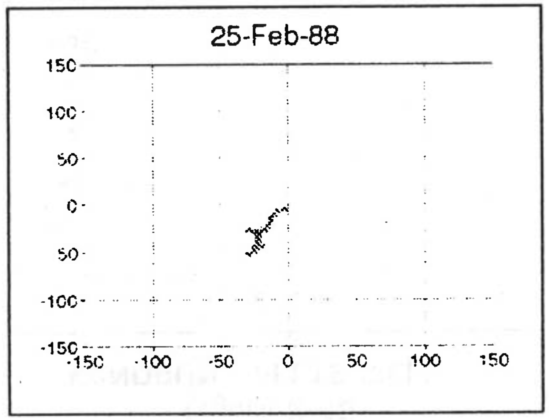


Figure K-52
WINDRUN - FELTS FIELD

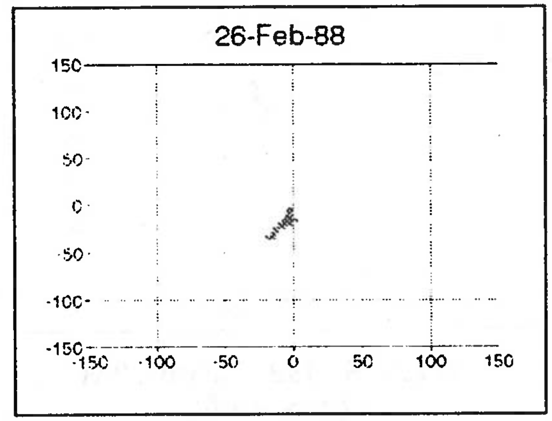


Figure K-53
WINDRUN - FELTS FIELD

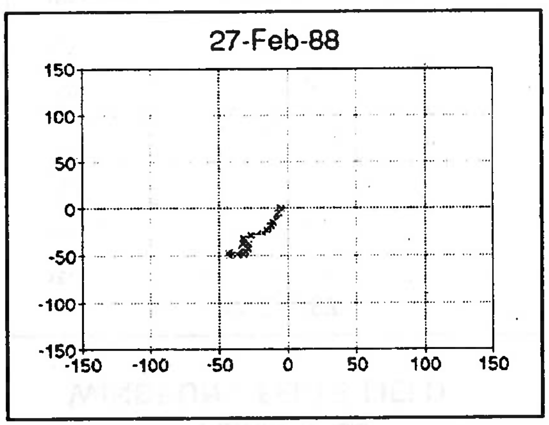


Figure K-54
WINDRUN - FELTS FIELD

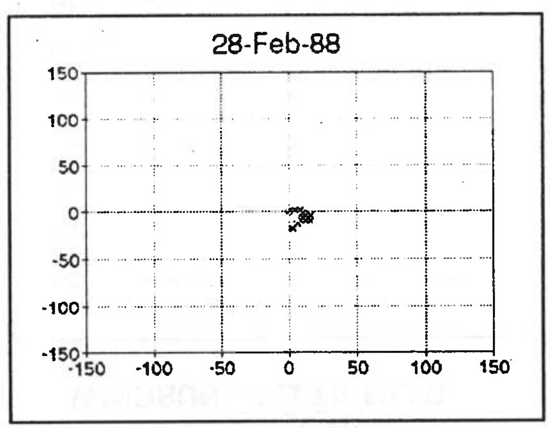


Figure K-55
WINDRUN - FELTS FIELD

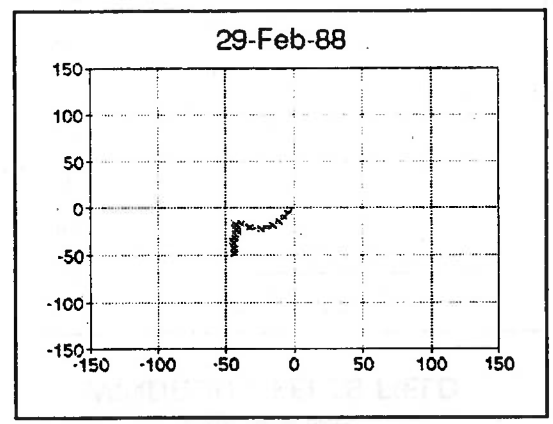


Figure K-56
WINDRUN - FELTS FIELD

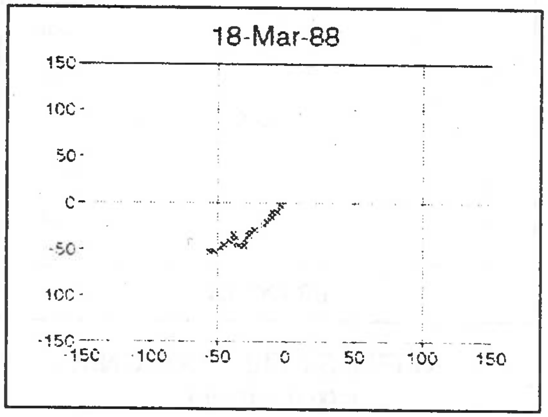


Figure K-57
WINDRUN - FELTS FIELD

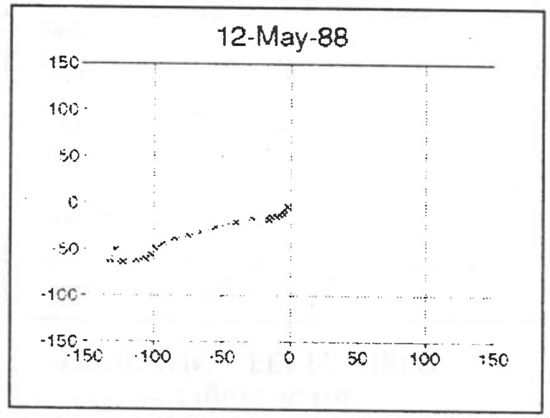


Figure K-58
WINDRUN - FELTS FIELD

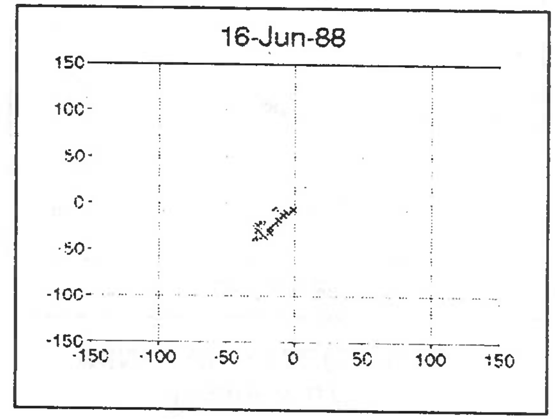


Figure K-59
WINDRUN - FELTS FIELD

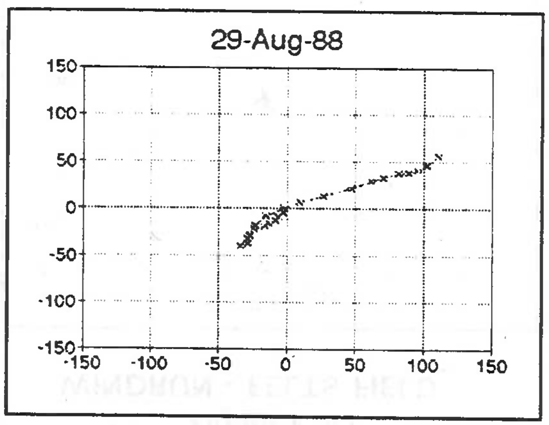


Figure K-60
WINDRUN - FELTS FIELD

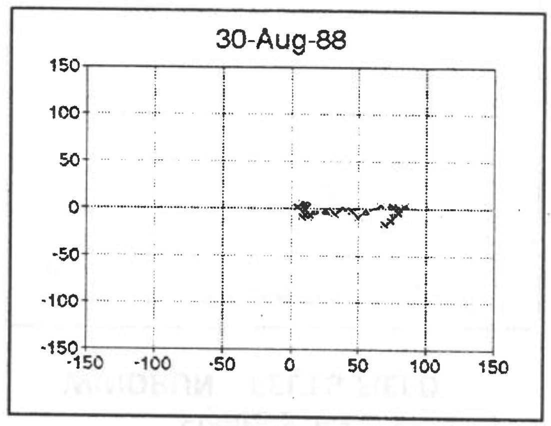


Figure K-61
WINDRUN - FELTS FIELD

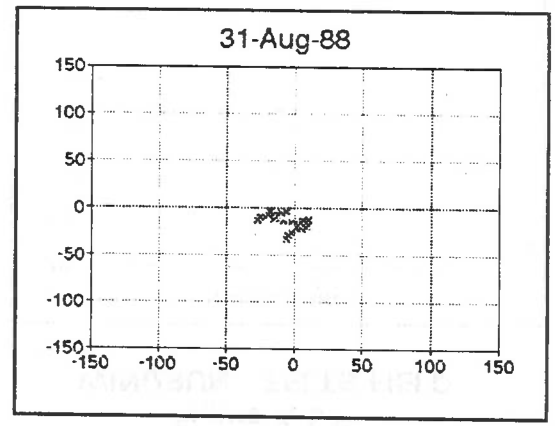


Figure K-62
WINDRUN - FELTS FIELD

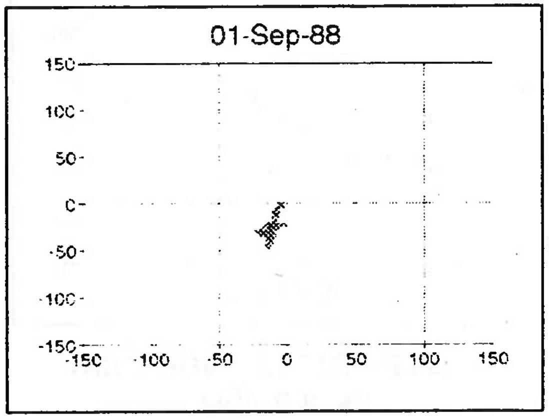


Figure K-63
WINDRUN - FELTS FIELD

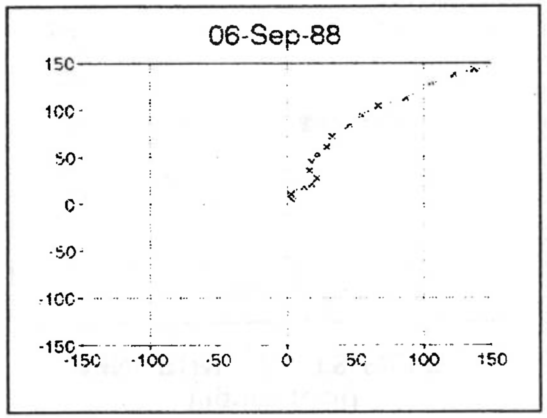


Figure K-64
WINDRUN - FELTS FIELD

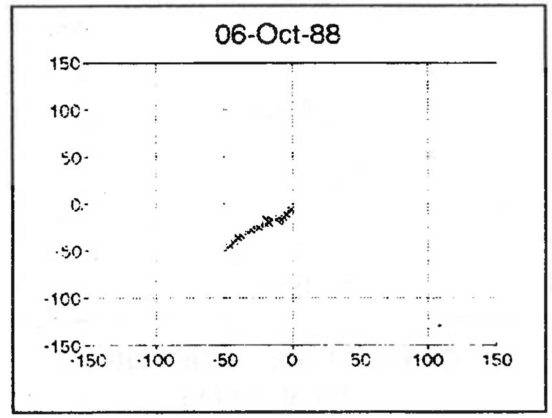


Figure K-65
WINDRUN - FELTS FIELD

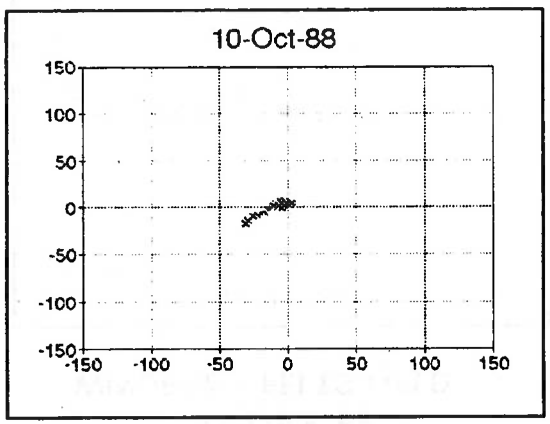


Figure K-66
WINDRUN - FELTS FIELD

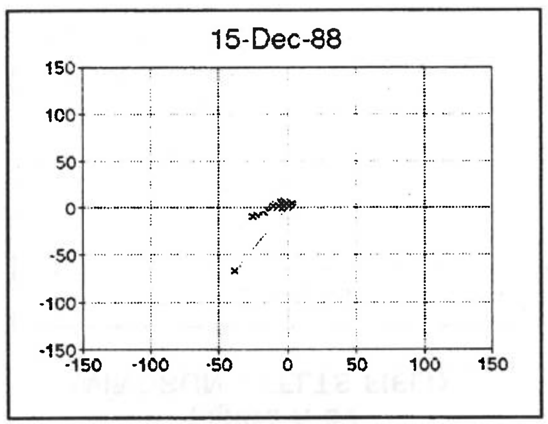


Figure K-67
WINDRUN - FELTS FIELD

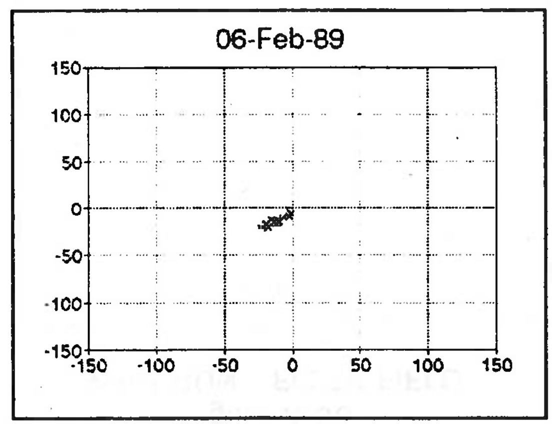


Figure K-68
WINDRUN - FELTS FIELD

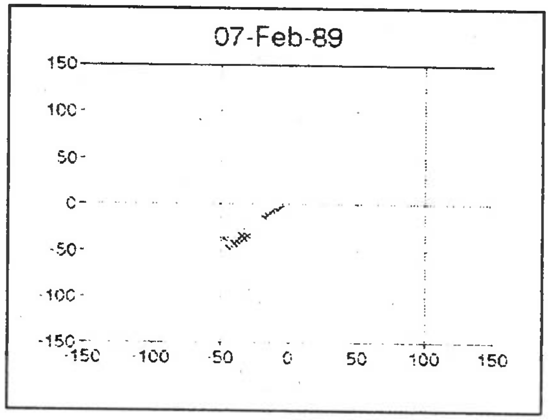


Figure K-69
WINDRUN - FELTS FIELD

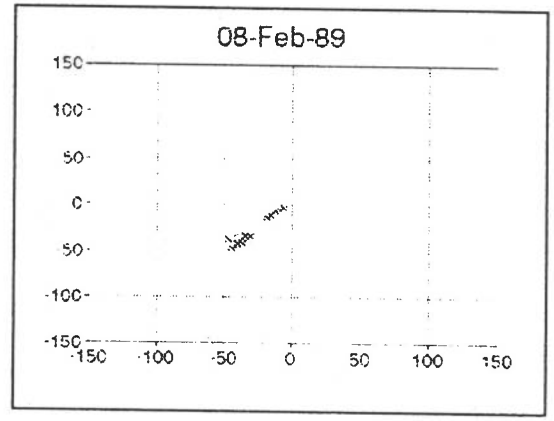


Figure K-70
WINDRUN - FELTS FIELD

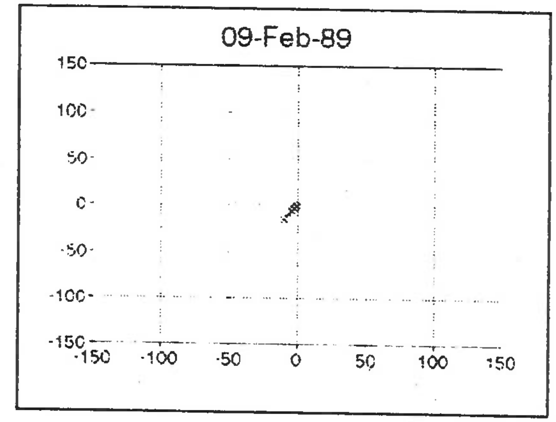


Figure K-71
WINDRUN - FELTS FIELD

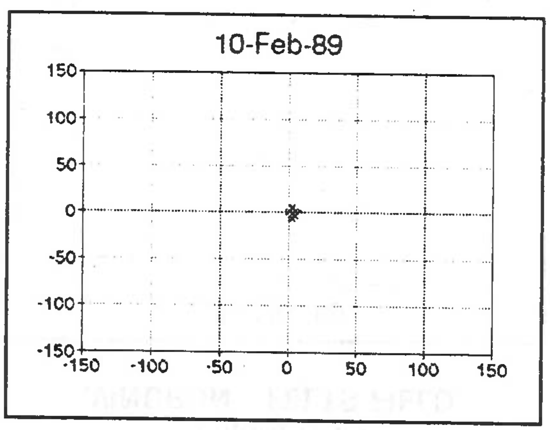


Figure K-72
WINDRUN - FELTS FIELD

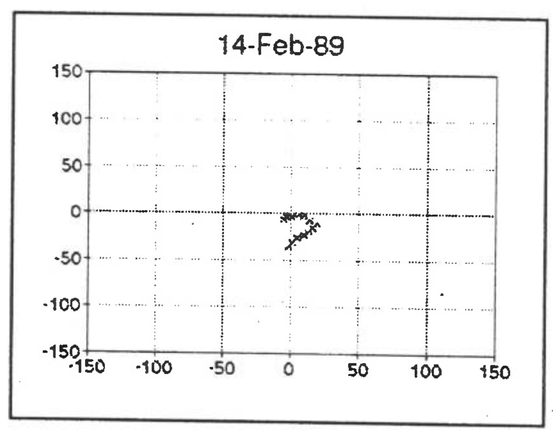


Figure K-73
WINDRUN - FELTS FIELD

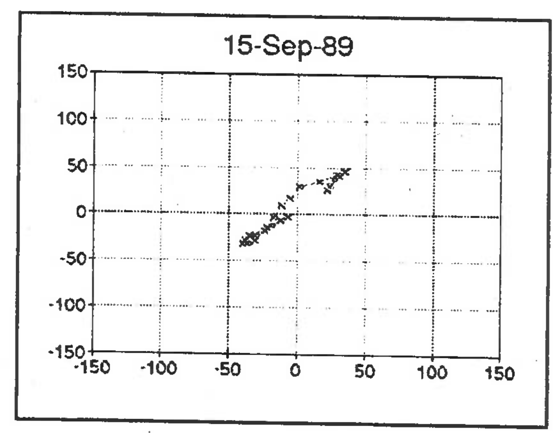


Figure K-74
WINDRUN - FELTS FIELD

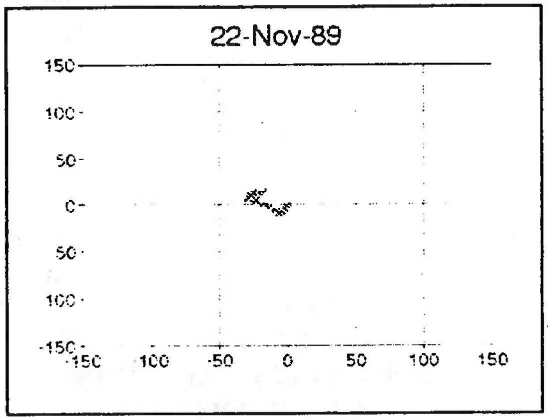


Figure K-75
SPOKANE PM_{10} NONATTAINMENT AREA SHOWING THE WYNDVALLEY MODELLING DOMAIN WITH GRID CELL NUMBERS

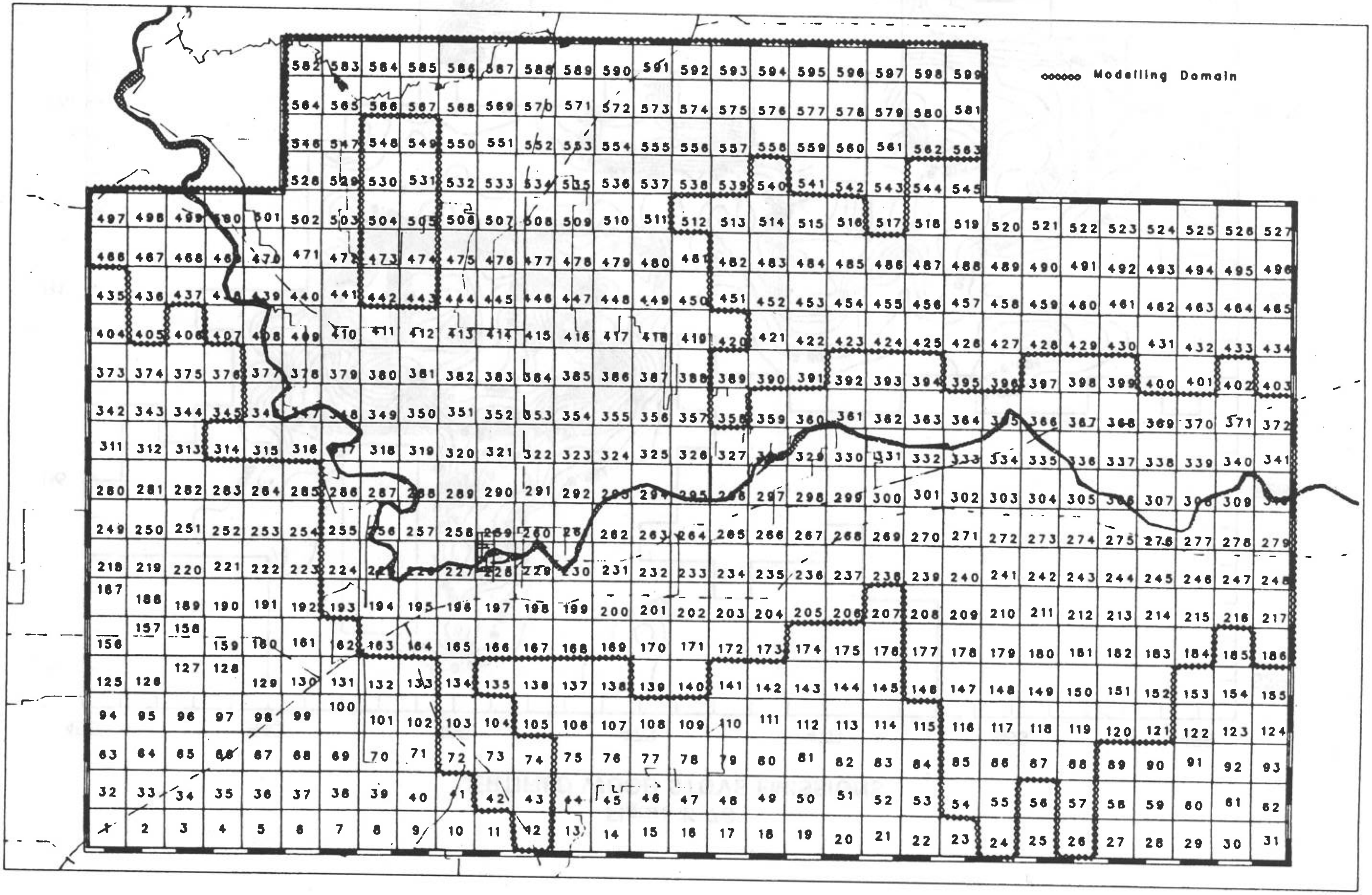


Figure K-76
CERTIFIED WOOD STOVE EMISSIONS

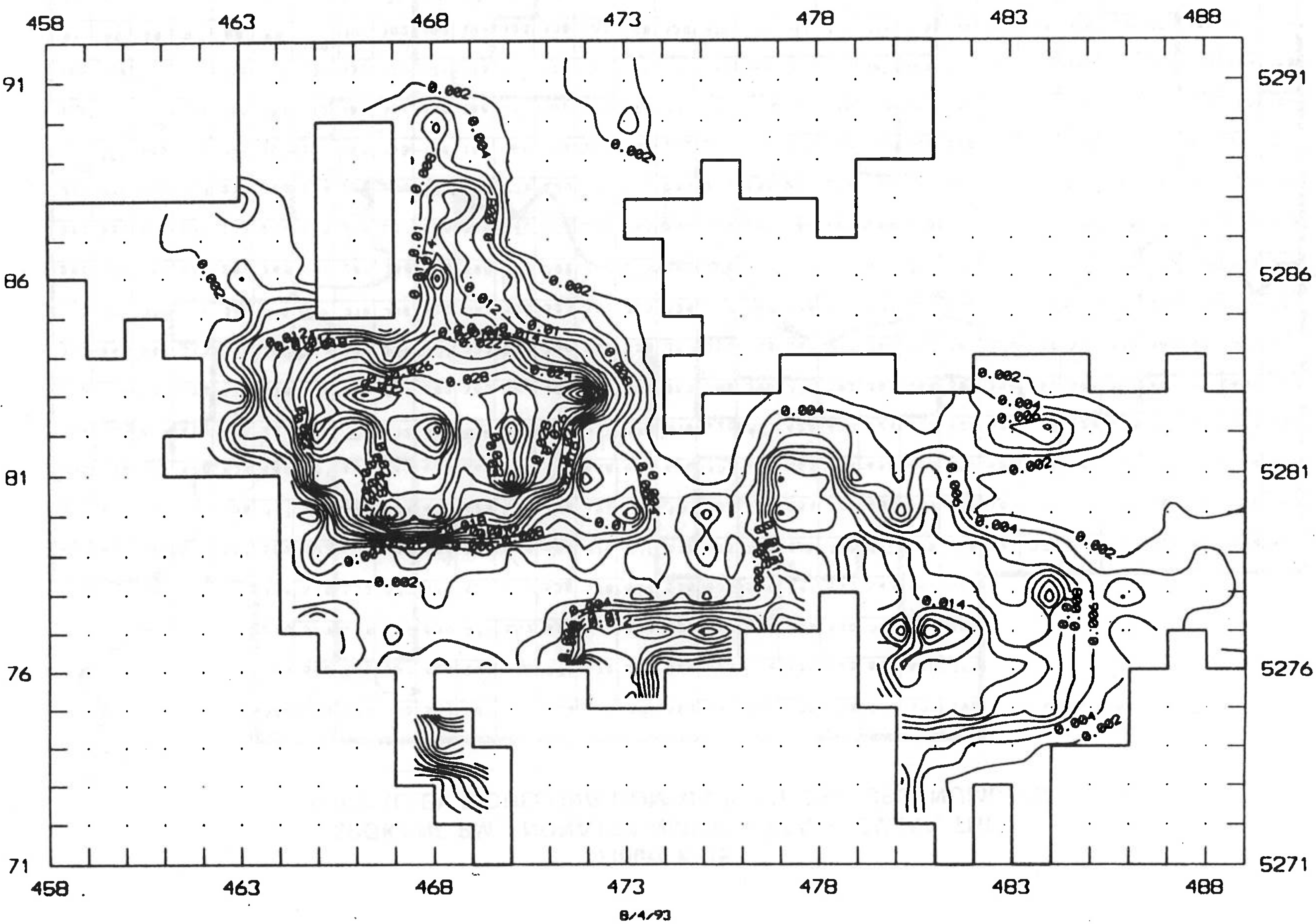


Figure K-77
UNCERTIFIED WOOD STOVE EMISSIONS

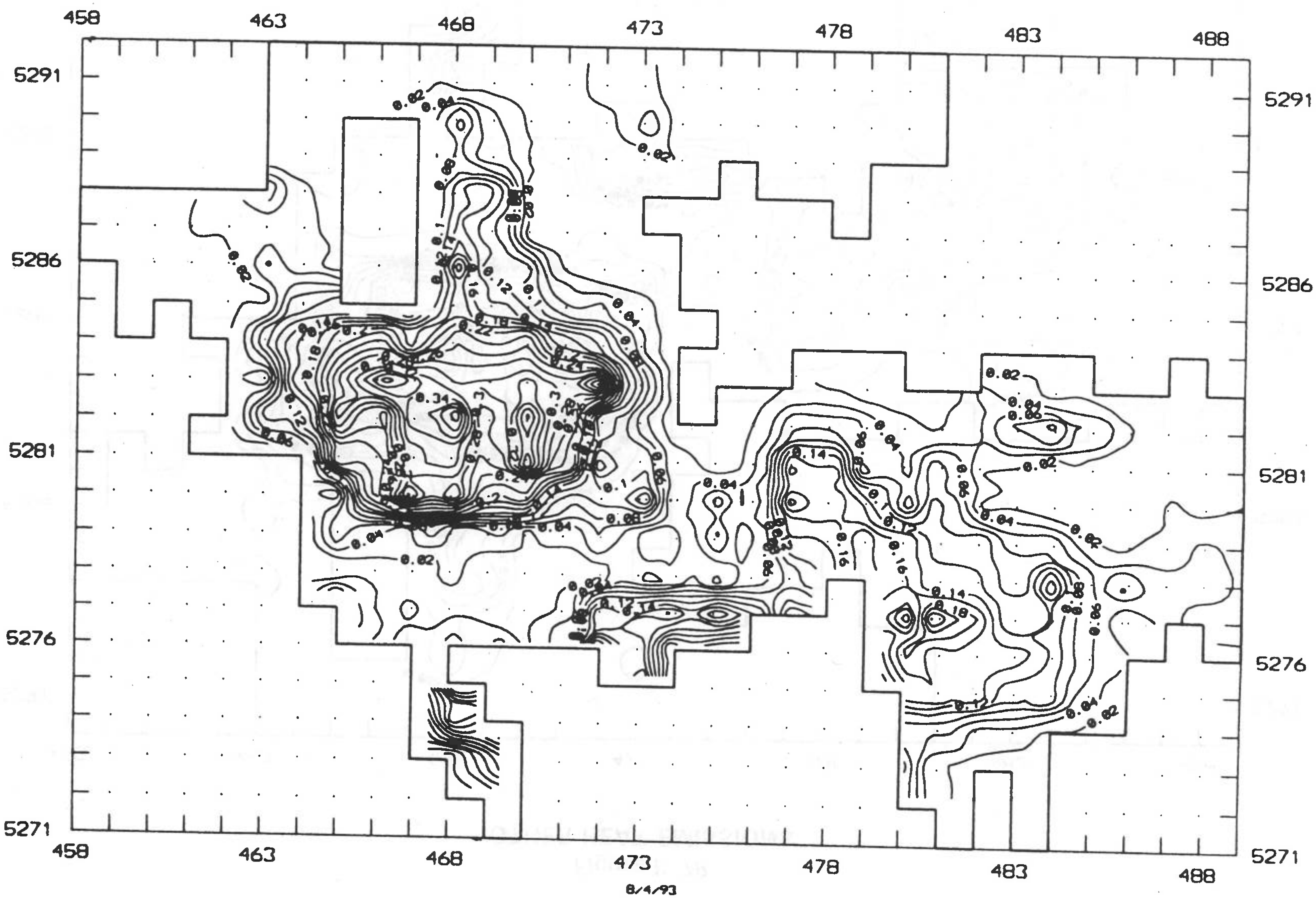


Figure K-78
OTHER HEAT EMISSIONS

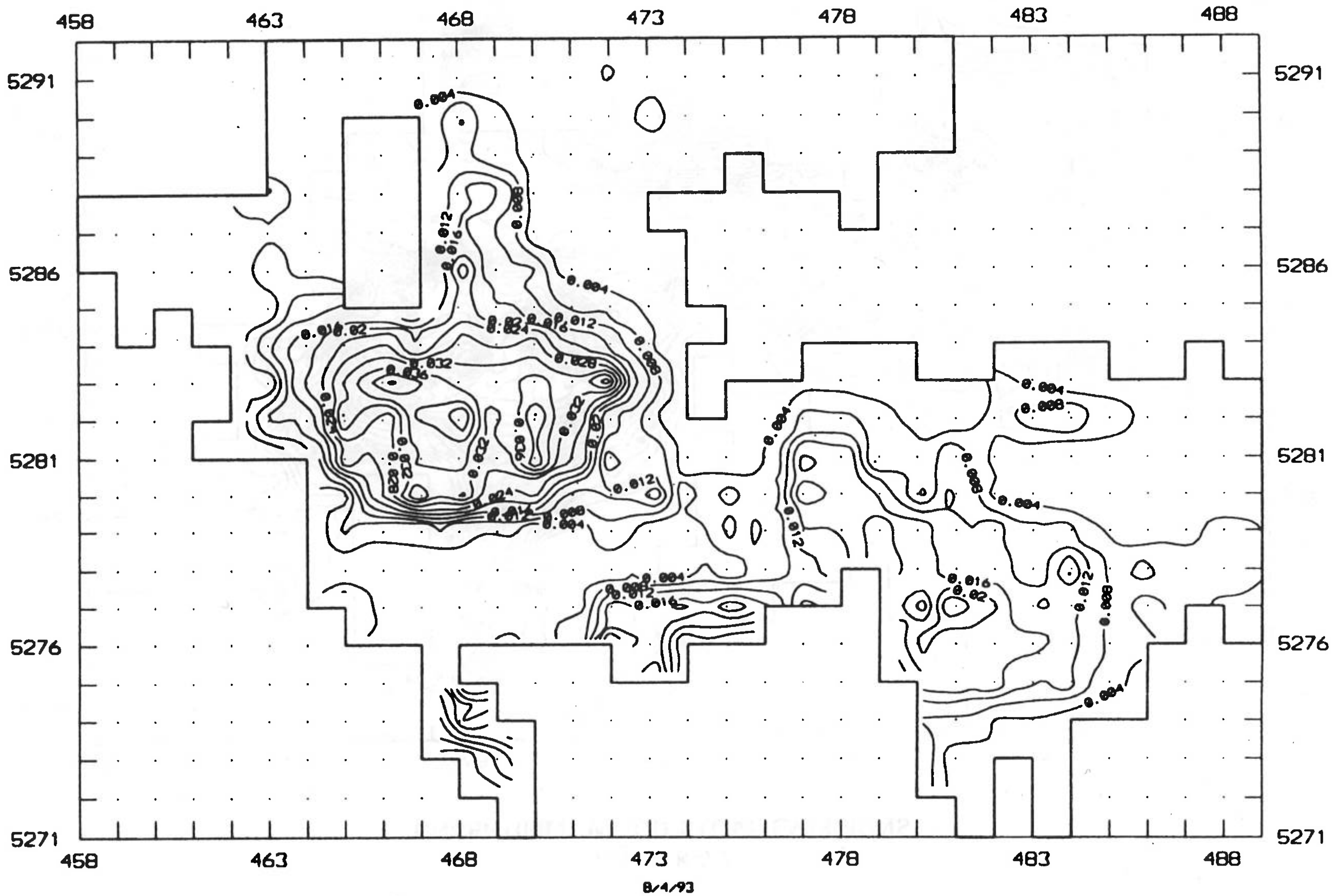


Figure K-79
HOURLY EMISSION RATES

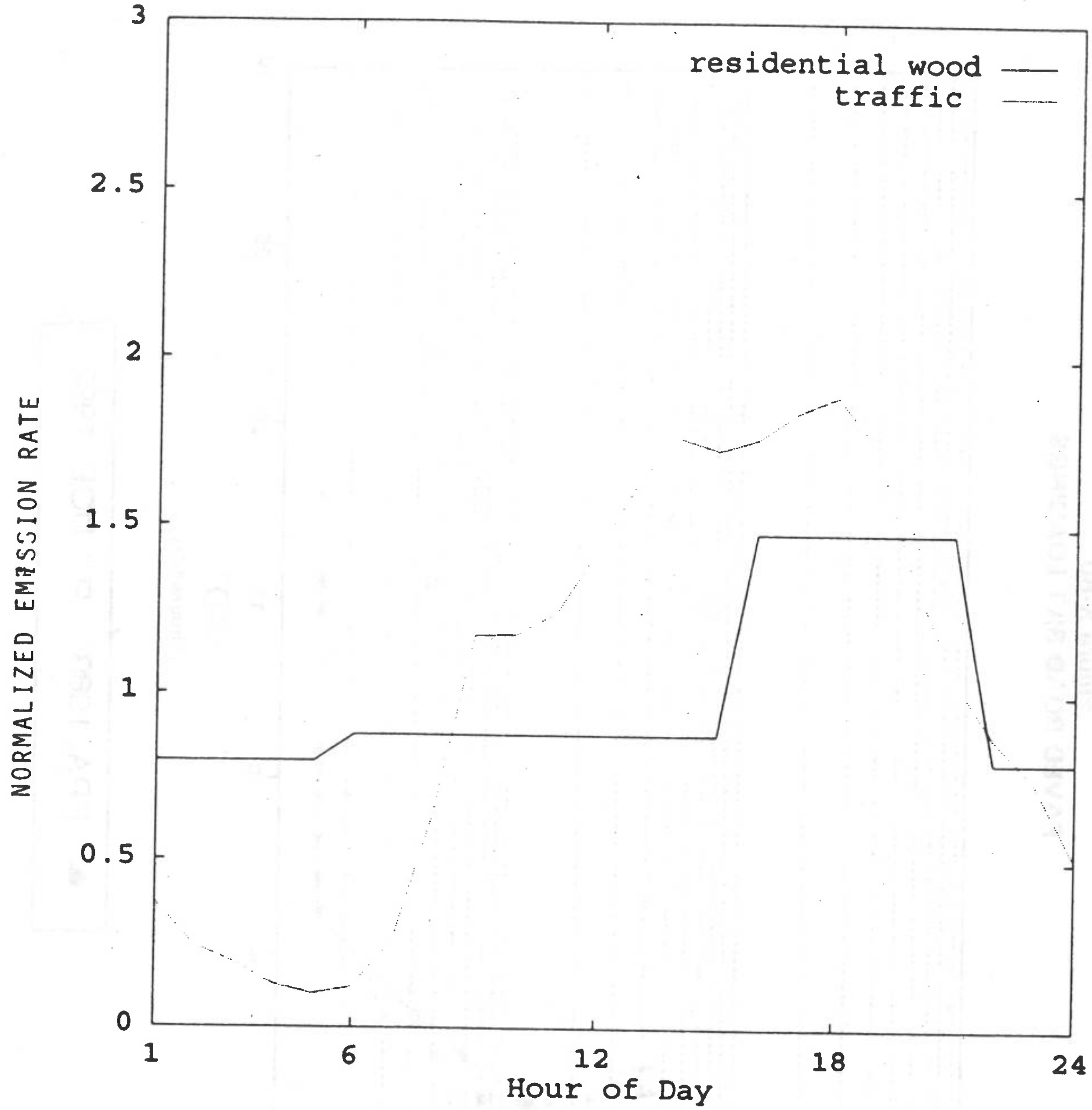


Figure K-80
PAVED ROAD SILT LOADINGS

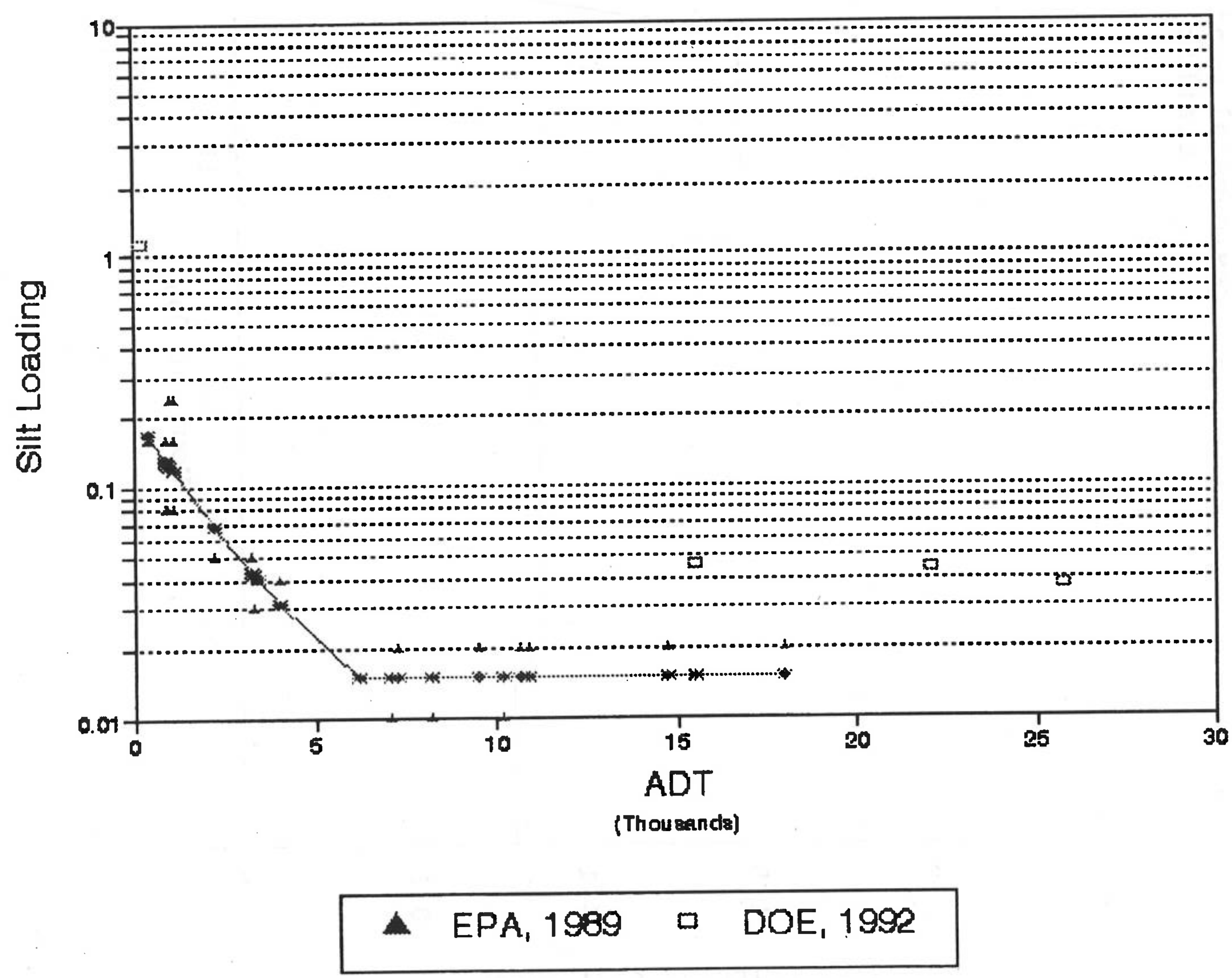


Figure K-81
UNPAVED ROAD SURVEY, SPEED VS. TRAFFIC COUNT

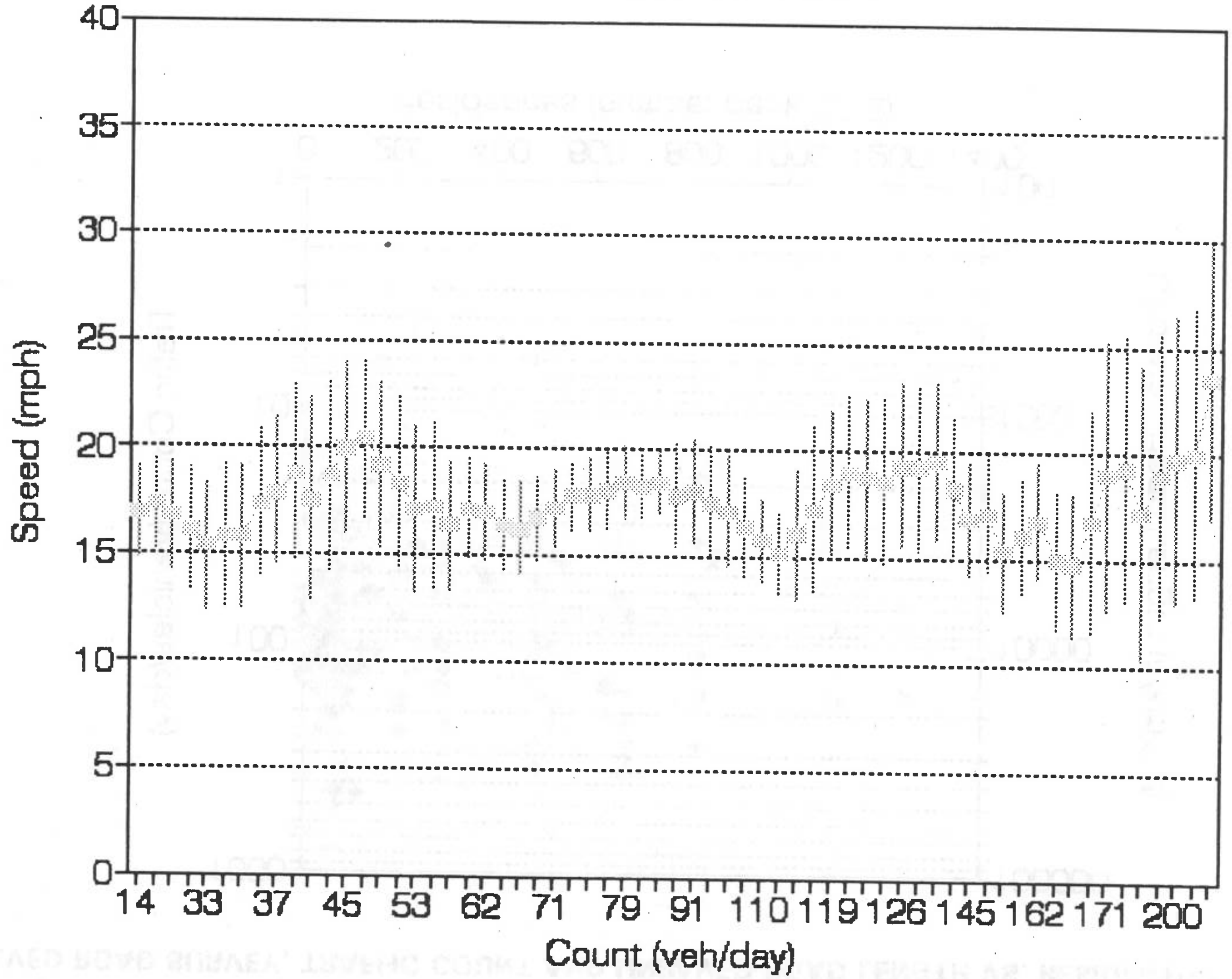


Figure K-82

UNPAVED ROAD SURVEY, TRAFFIC COUNT AND UNPAVED ROAD LENGTH VS. RESIDENTIAL DENSITY

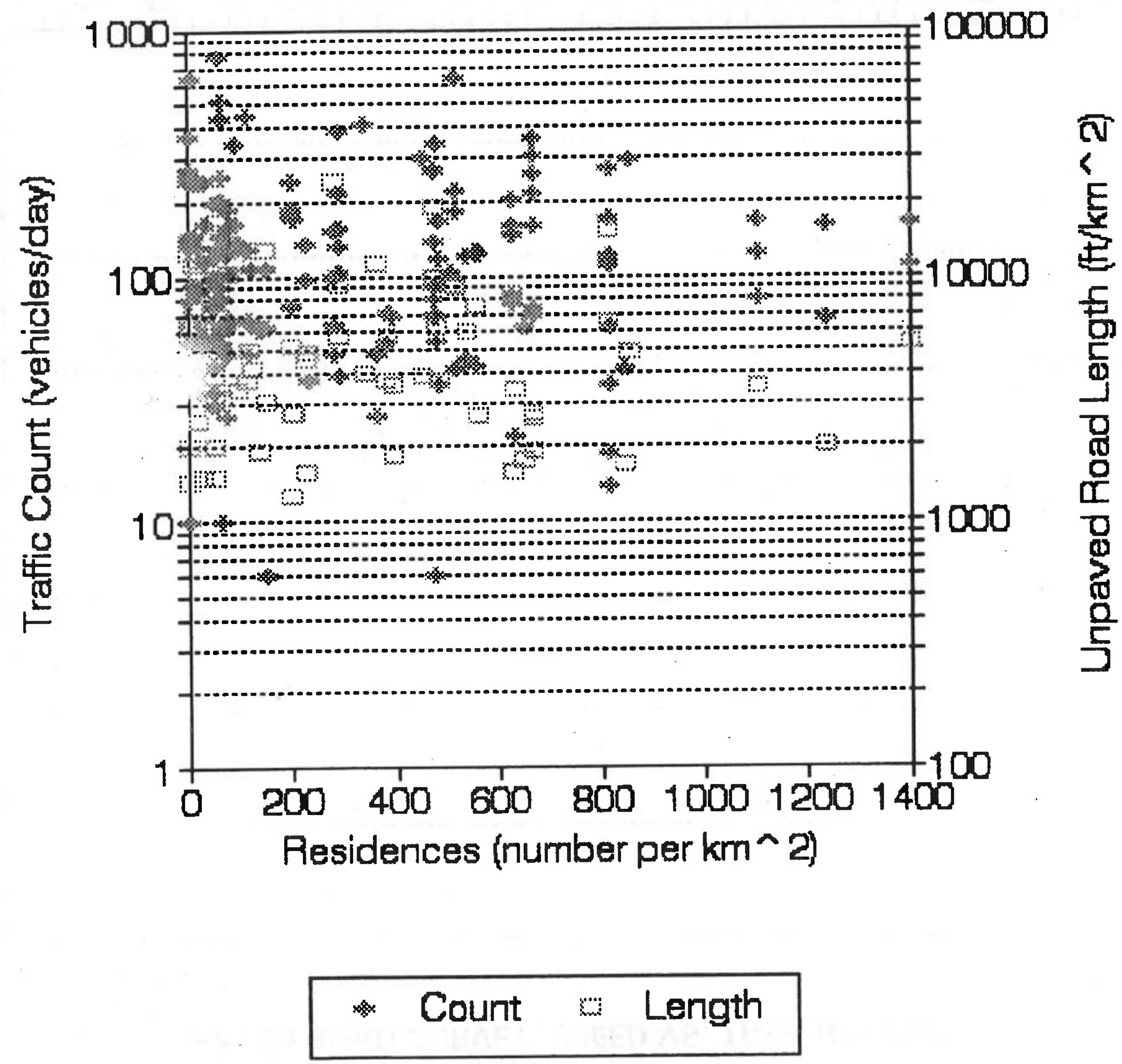


Figure K-83
CHEMICAL ANALYSIS OF CROWN ZELLERBACH FILTERS, 04 FEB 92

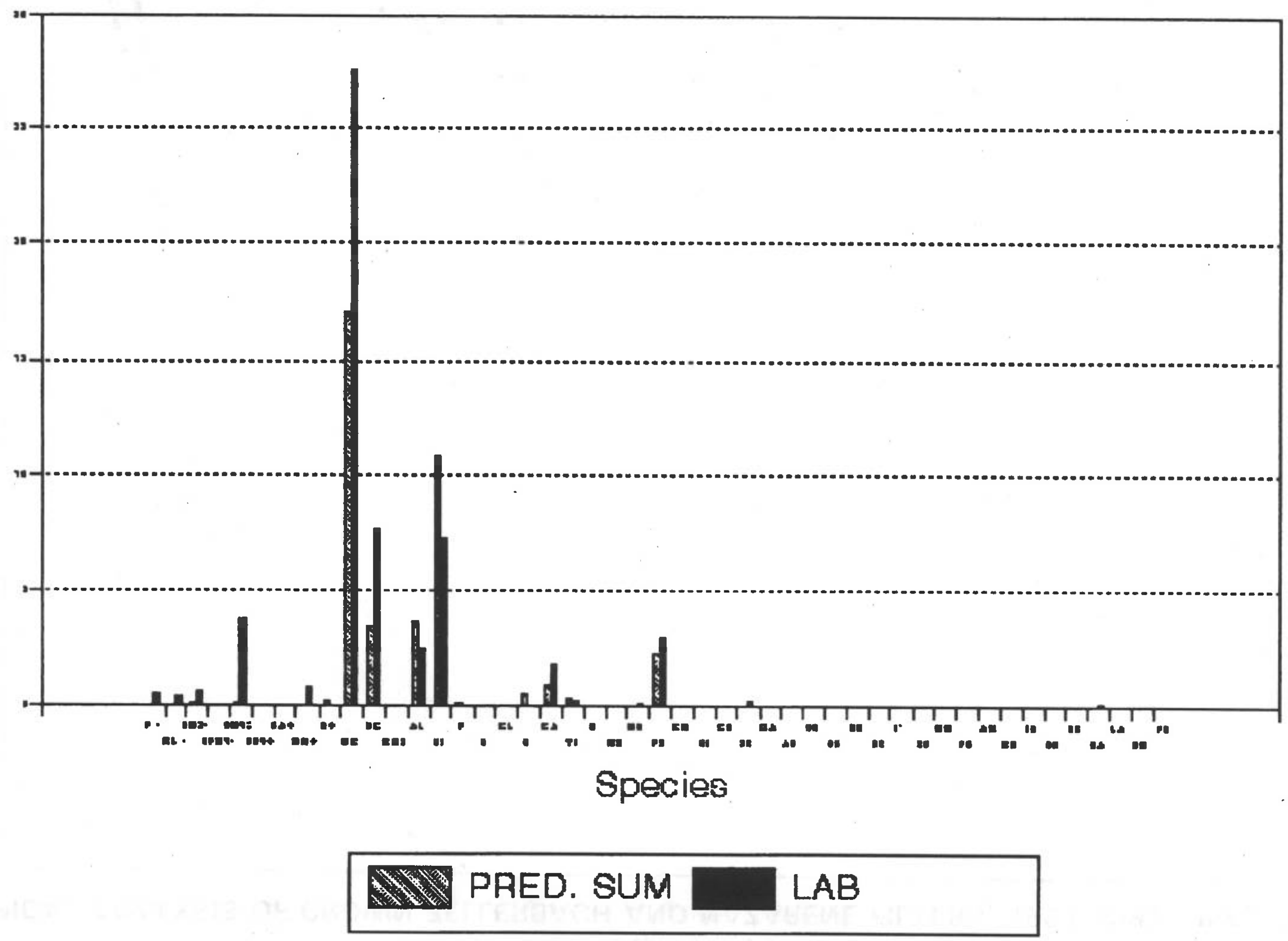


Figure K-84

CHEMICAL ANALYSIS OF CROWN ZELLERBACH AND NAZARENE FILTERS, 1991-1992 - PM_{10} VS. SULFATE

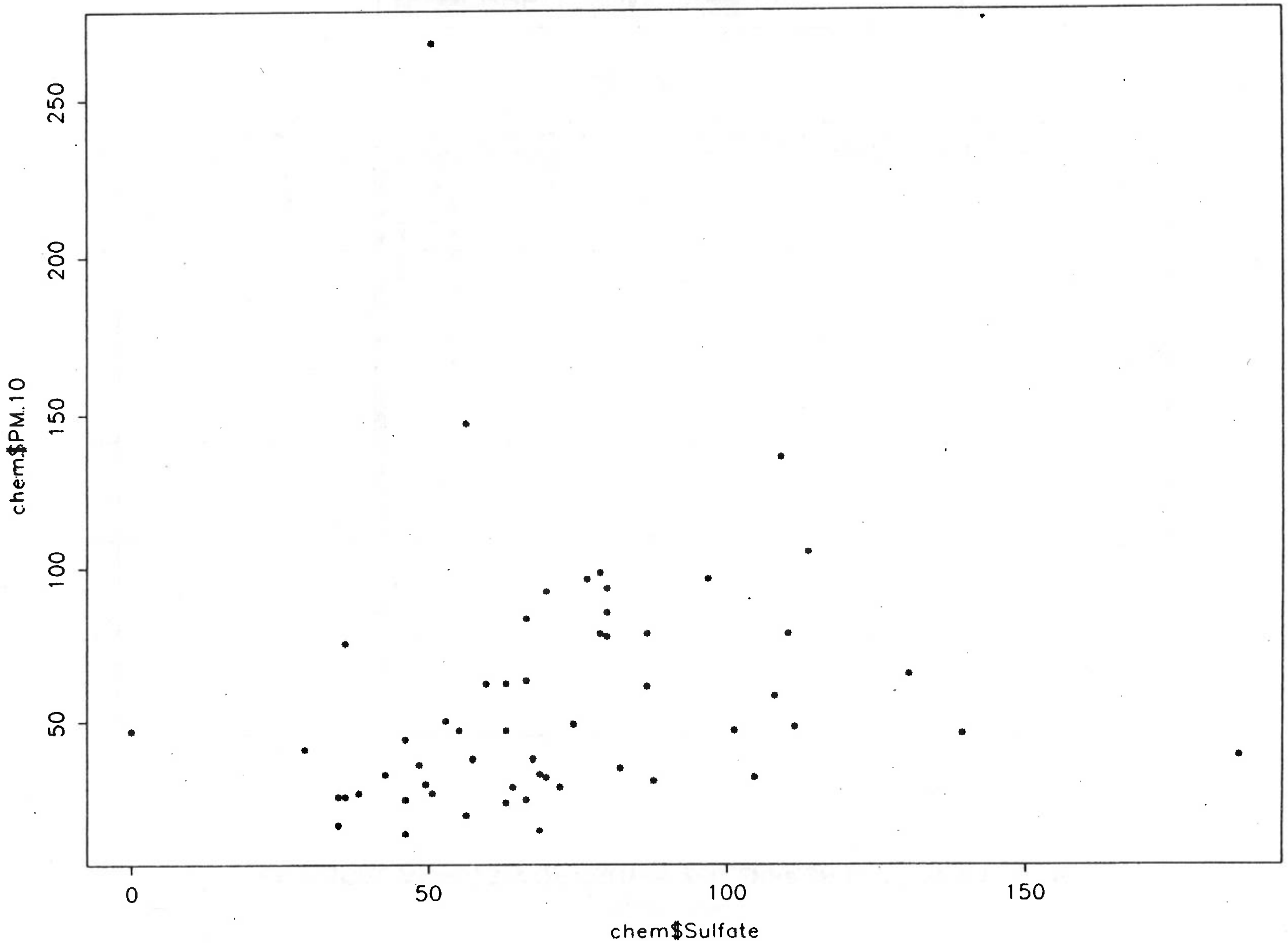


Figure K-85
CHEMICAL ANALYSIS OF CROWN ZELLERBACH AND NAZARENE FILTERS, 1991-1992 - FLOURIDE VS. SULFATE

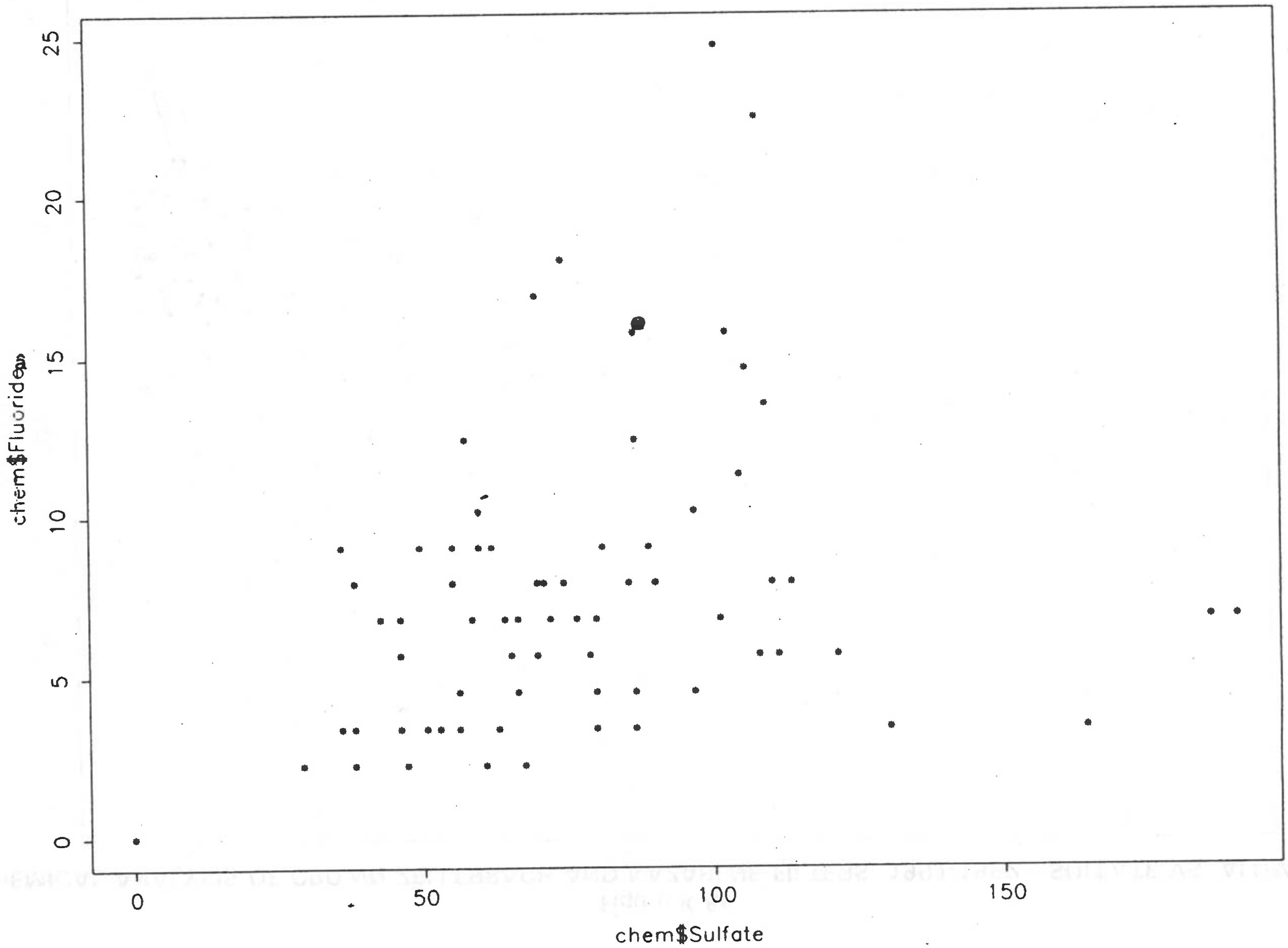


Figure K-86

CHEMICAL ANALYSIS OF CROWN ZELLERBACH AND NAZARENE FILTERS, 1991-1992 - SULFATE VS. ALUMINUM

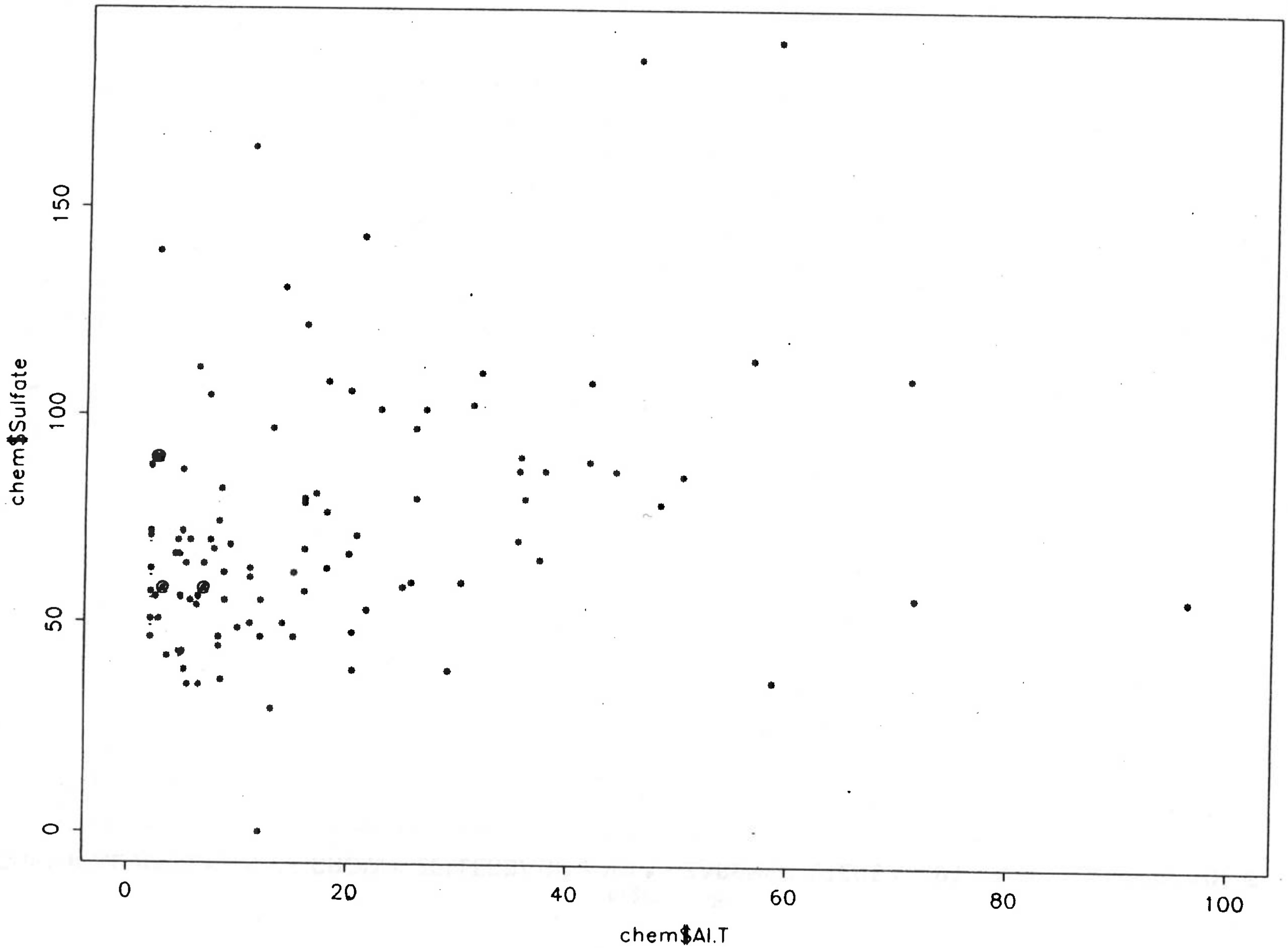


Figure K-87

CHEMICAL ANALYSIS OF CROWN ZELLERBACH AND NAZARENE FILTERS, 1991-1992 - ALUMINUM VS. LOCATION

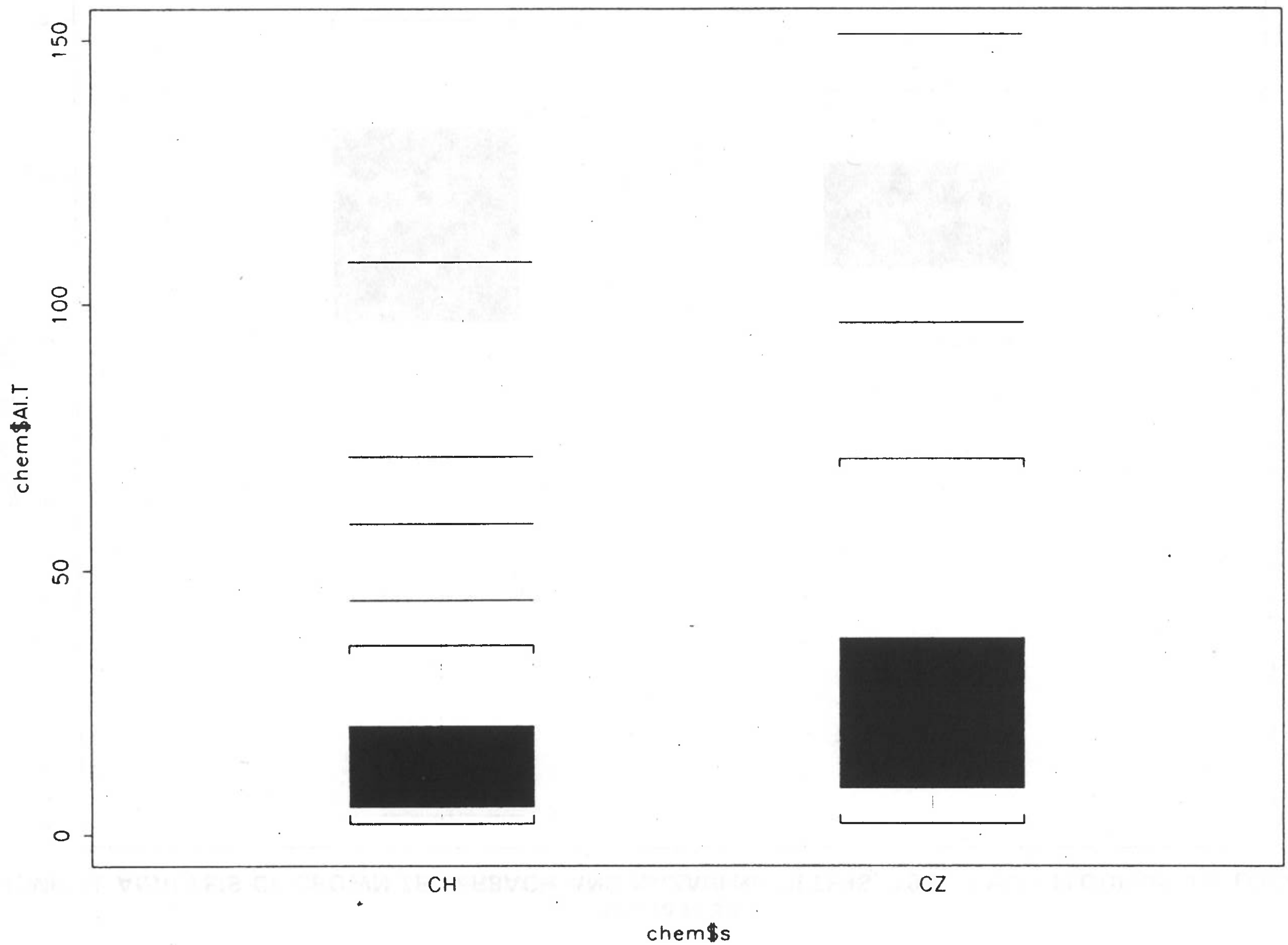


Figure K-88

CHEMICAL ANALYSIS OF CROWN ZELLERBACH AND NAZARENE FILTERS, 1991-1992 - FLOURIDE VS. LOCATION

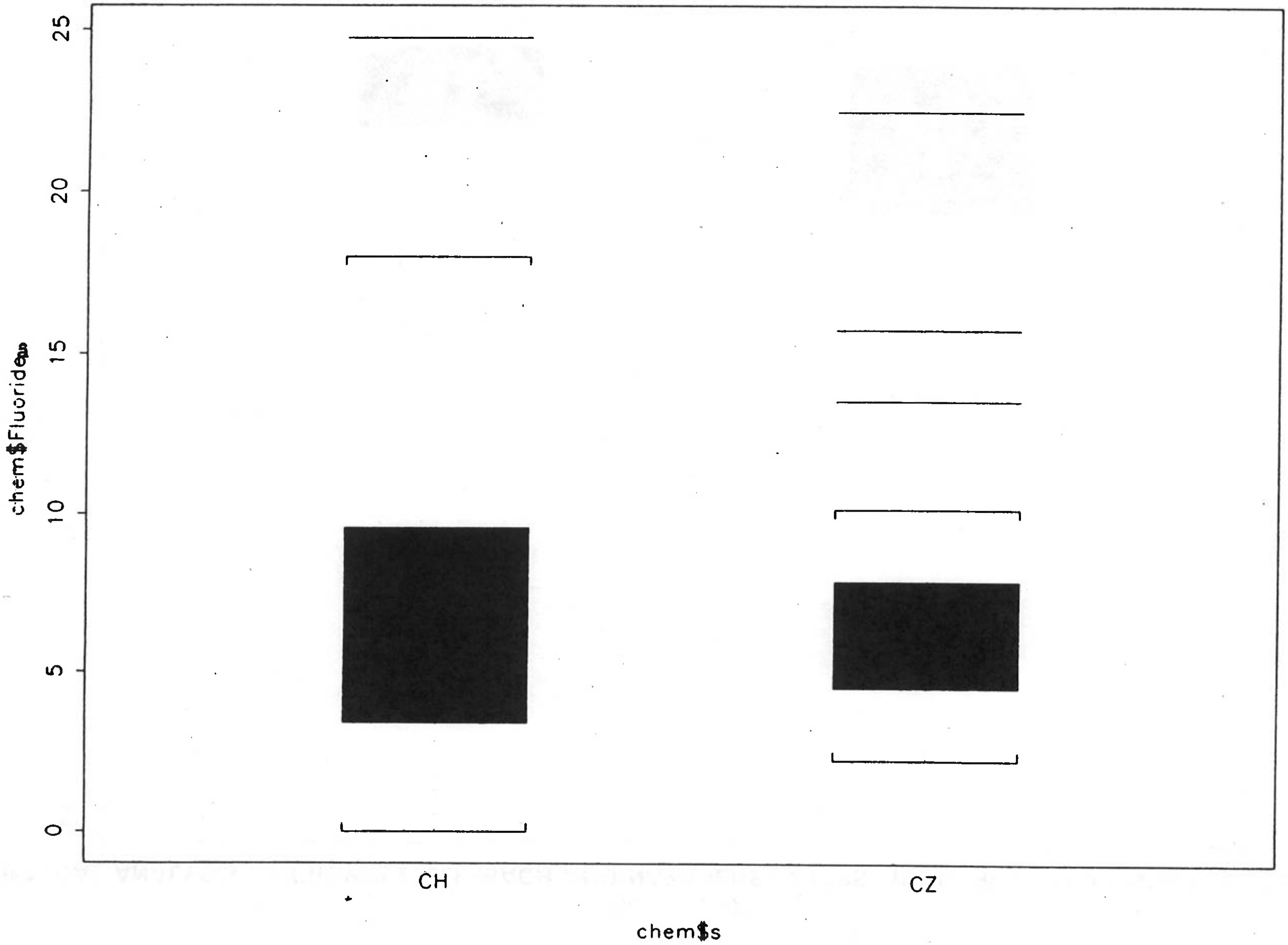


Figure K-89

CHEMICAL ANALYSIS OF CROWN ZELLERBACH AND NAZARENE FILTERS, 1991-1992 - SULFATE VS. DATE

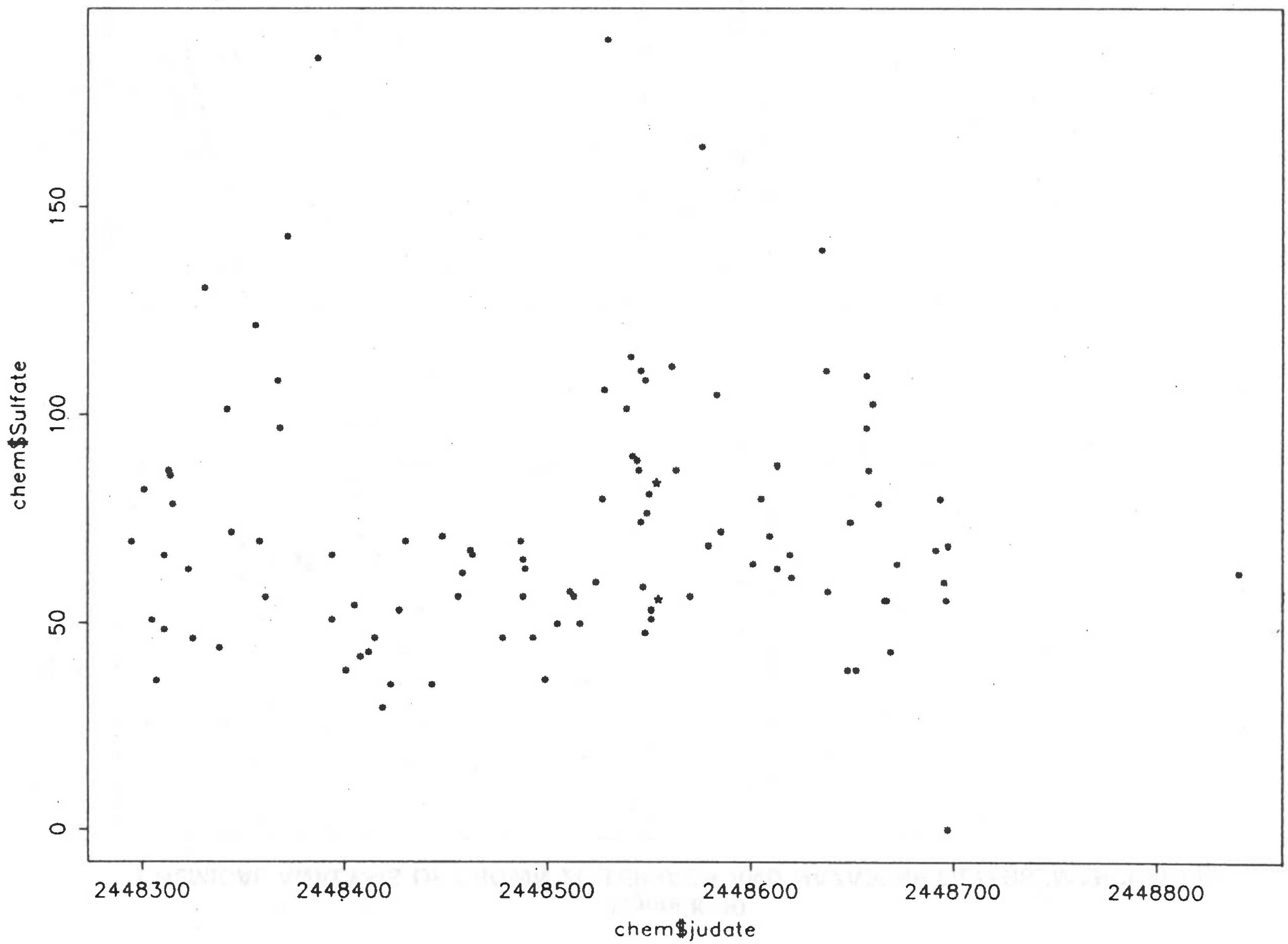


Figure K-90

CHEMICAL ANALYSIS OF CROWN ZELLERBACH AND NAZARENE FILTERS, MARCH 1993

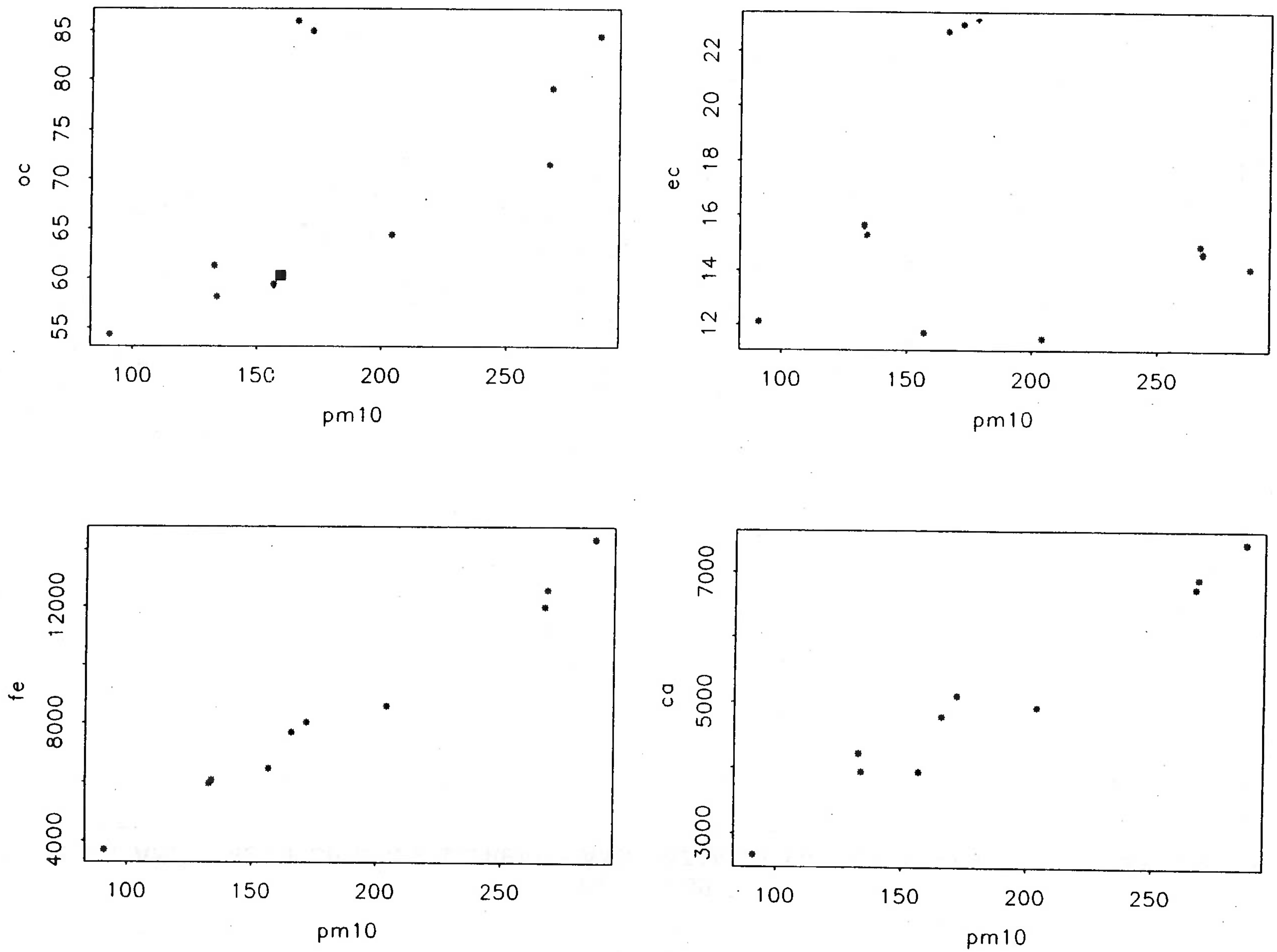


Figure K-91
MODEL COMPARISON AT CROWN ZELLERBACH

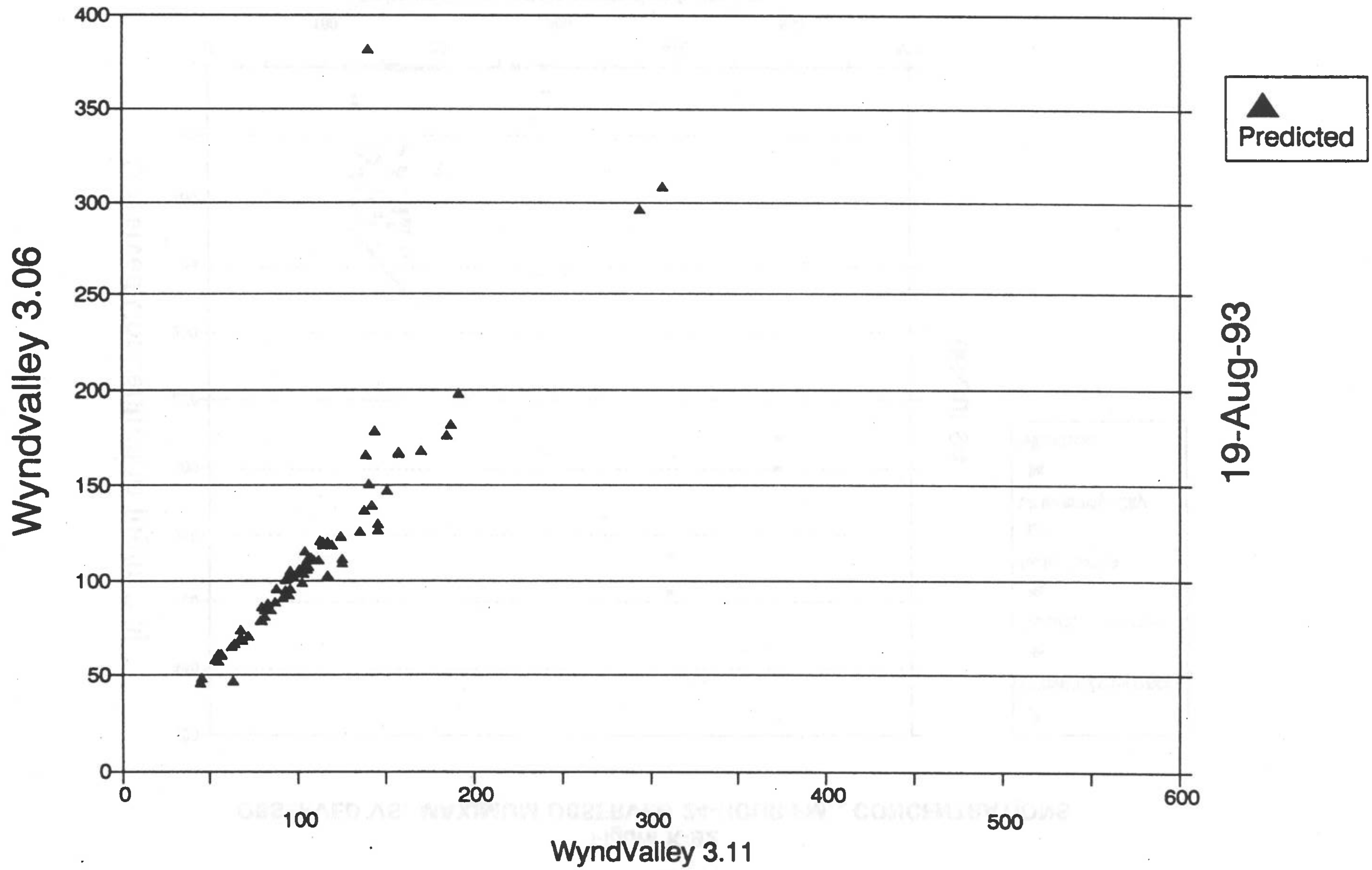


Figure K-92
OBSERVED VS. MAXIMUM OBSERVED 24-HOUR PM_{10} CONCENTRATIONS

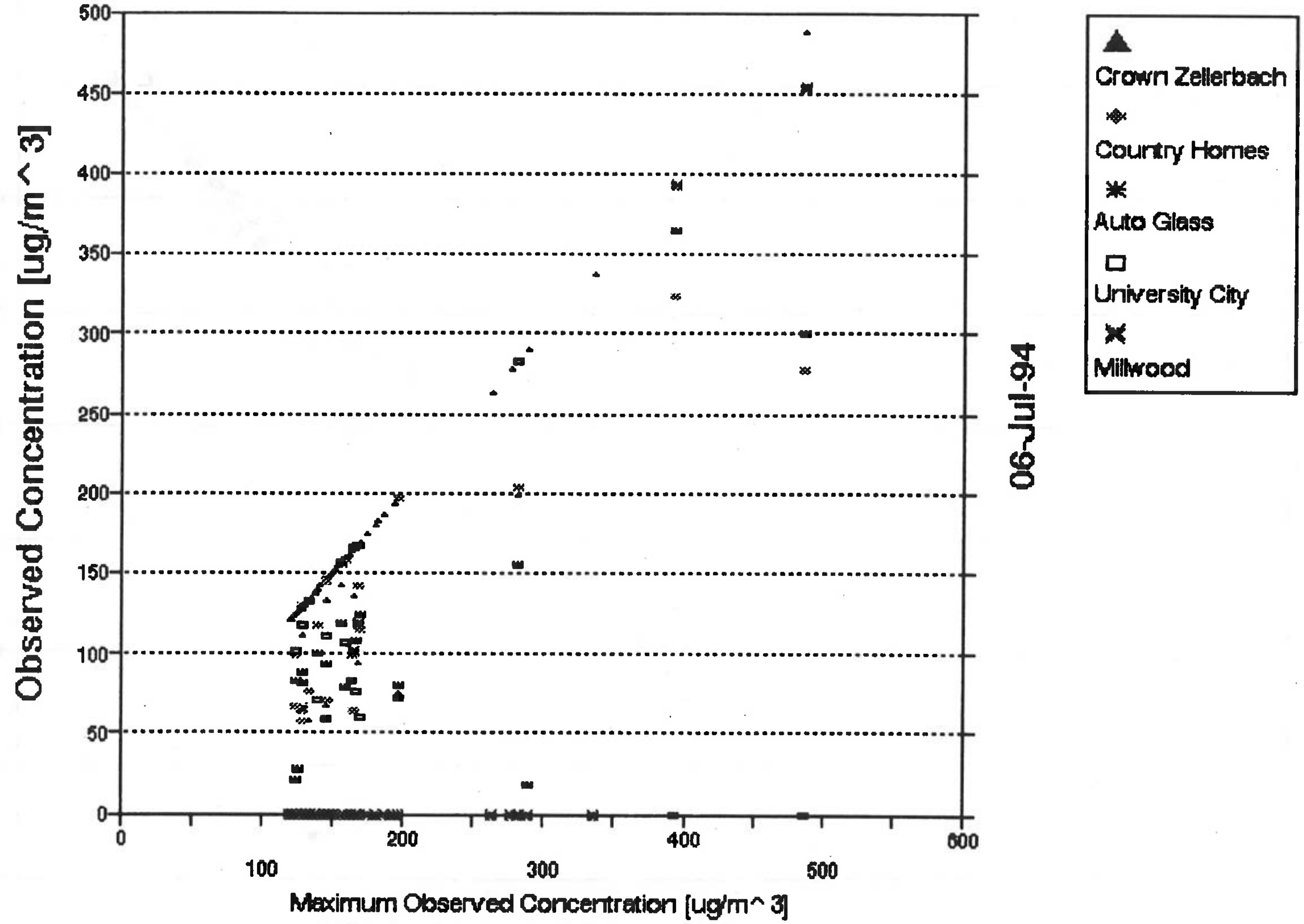


Figure K-93
OBSERVED VS. PREDICTED 24-HOUR PM_{10} CONCENTRATIONS AT CROWN ZELLERBACH

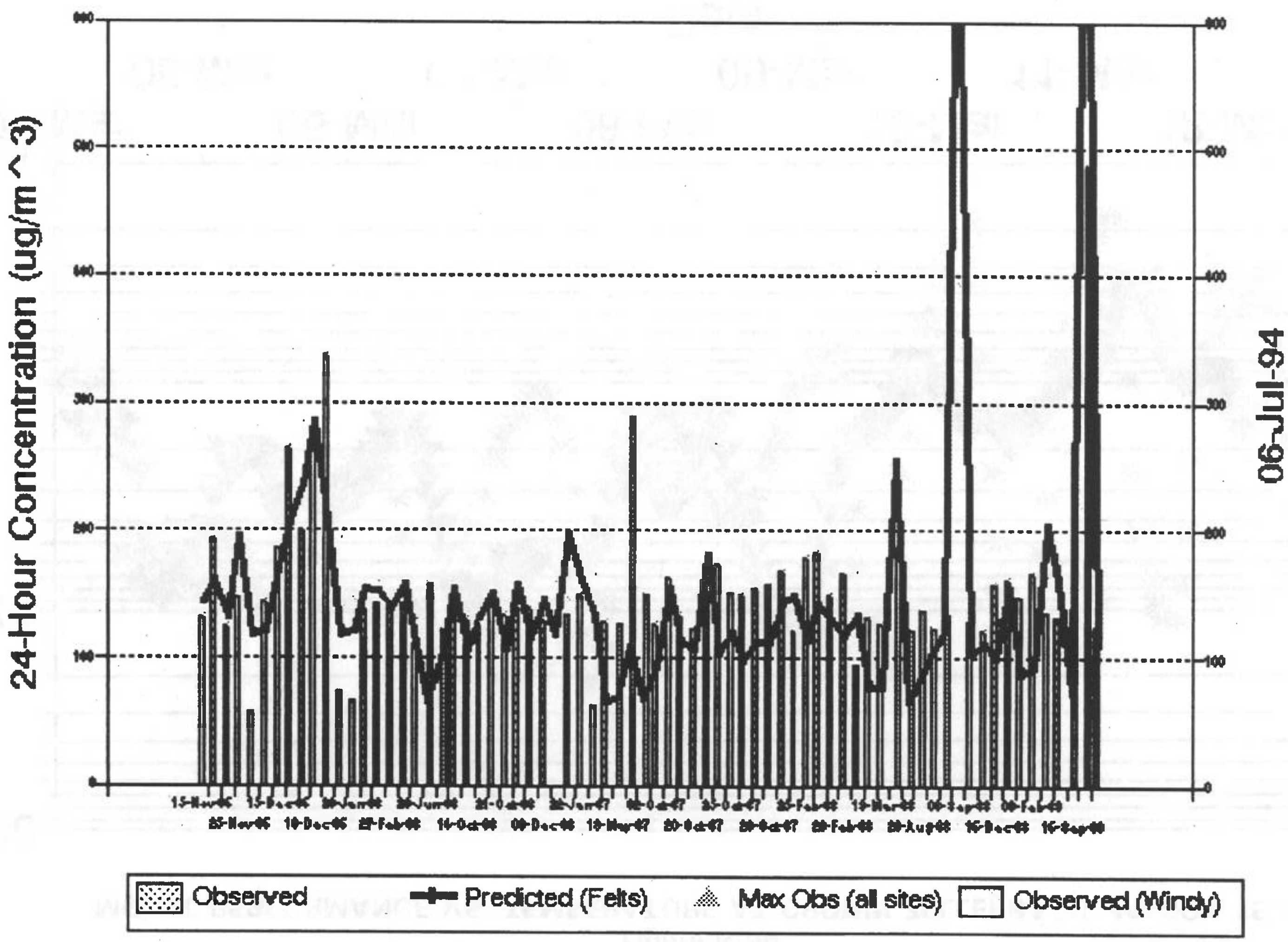


Figure K-94
MODEL PERFORMANCE VS. TEMPERATURE AT CROWN ZELLERBACH, MARCH 1993

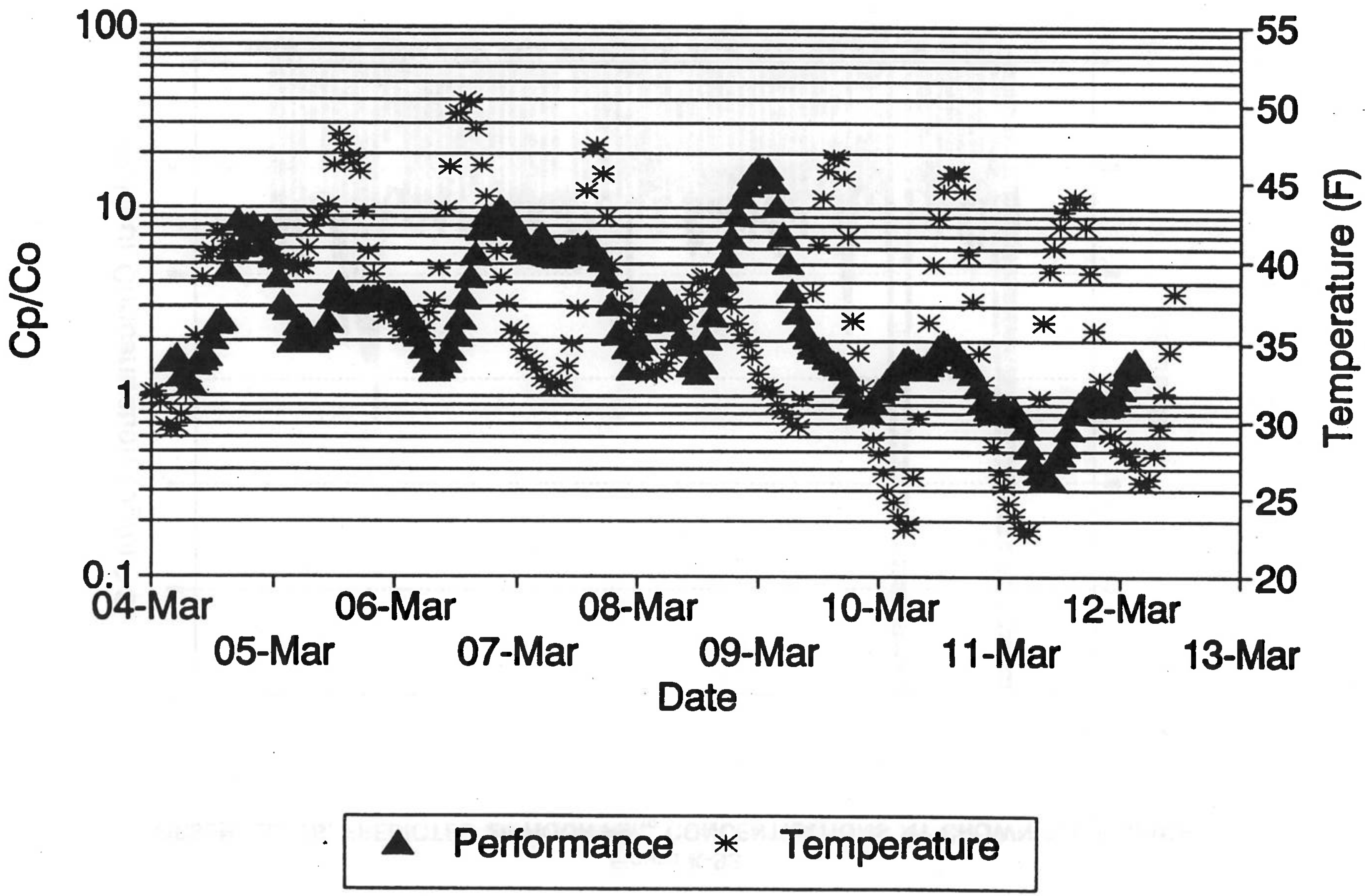
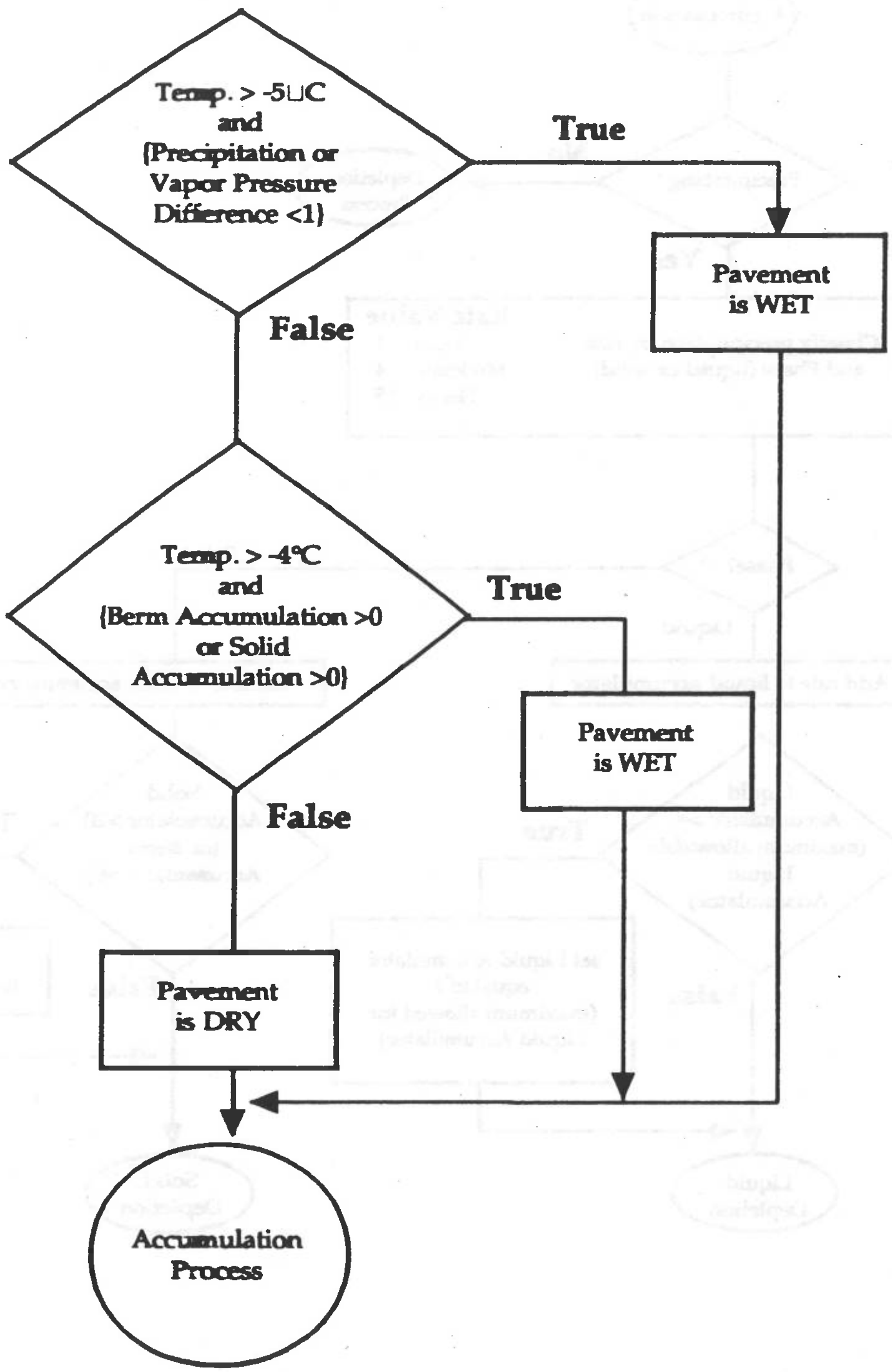


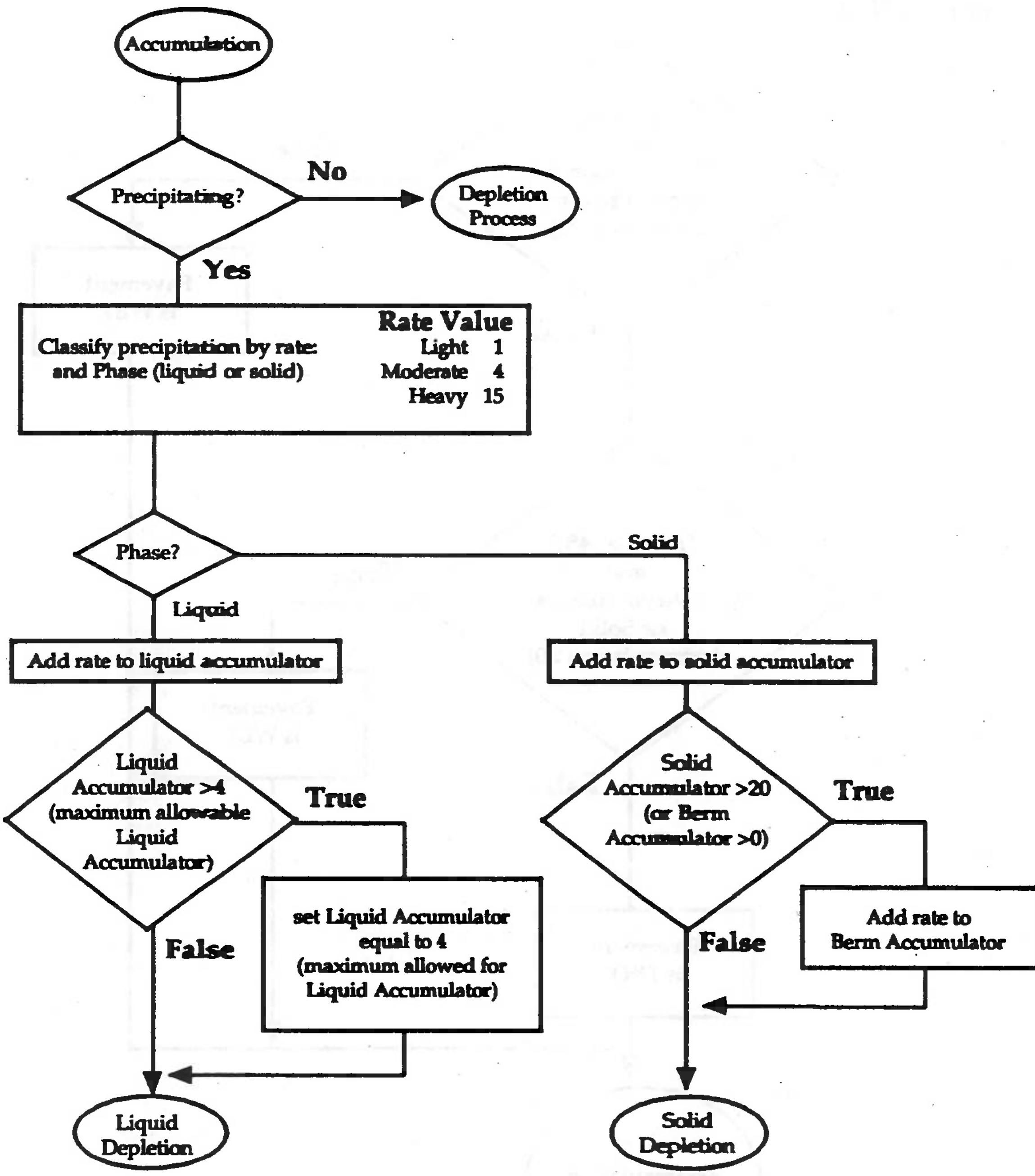
Figure K-95
MOISTURE ALGORITHM

Determine Pavement Condition

For Each Hour:



Accumulation Process



Depletion

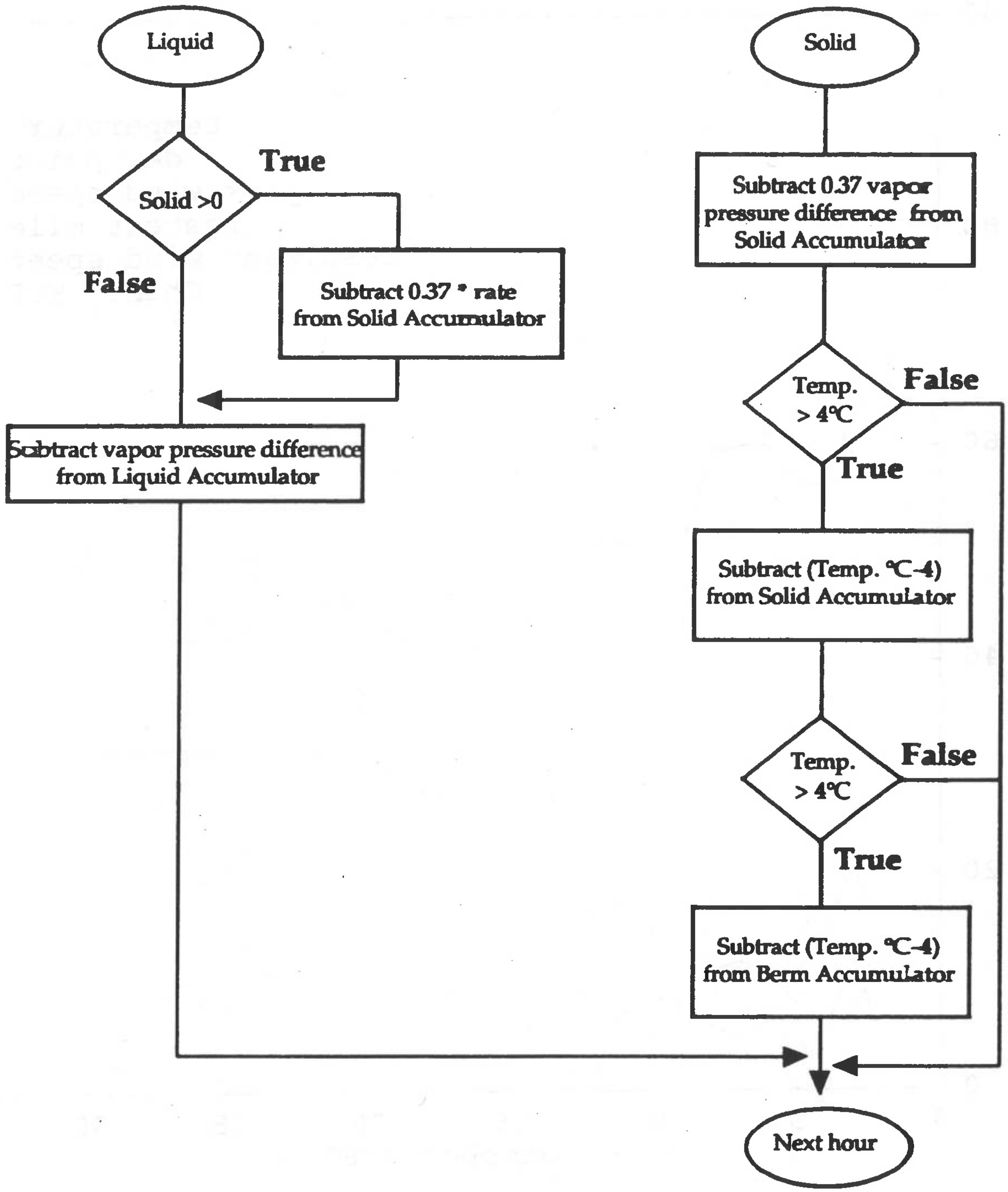

Liquid
Solid >0
True
False
Subtract 0.37 * rate from Solid Accumulator
Subtract vapor pressure difference from Liquid Accumulator
Solid
Subtract 0.37 vapor pressure difference from Solid Accumulator
Temp. > 4°C
False
True
Subtract (Temp. °C-4) from Solid Accumulator
Temp. > 4°C
False
True
Subtract (Temp. °C-4) from Berm Accumulator
Next hour

Figure K-96
METEOROLOGICAL CONDITIONS AT SPOKANE INTERNATIONAL AIRPORT AND TSP AT TURNBULL SLOUGH, 10 SEP 93

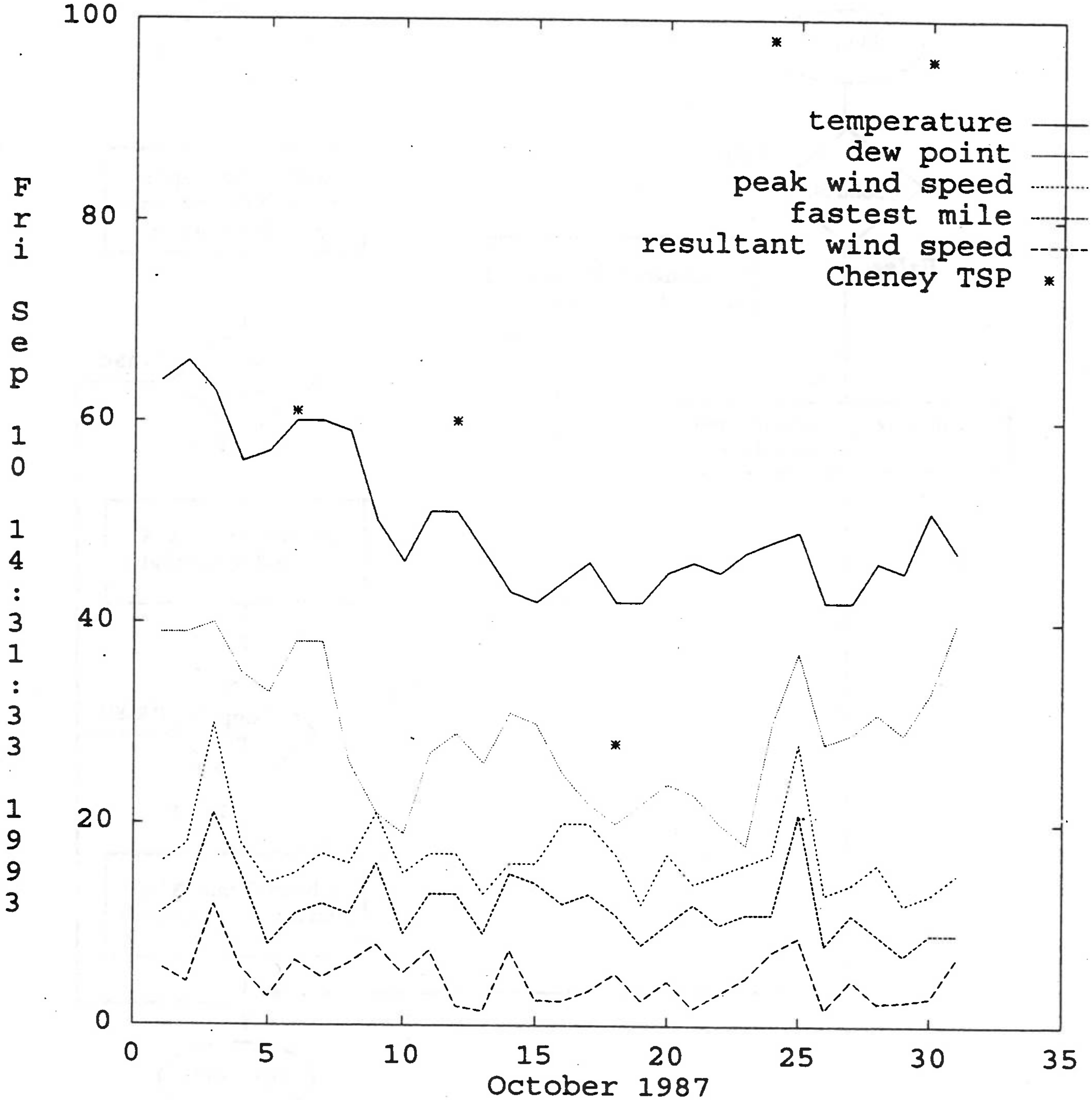


Figure K-97

MODEL PERFORMANCE VS. AVERAGE WIND SPEED AT CROWN ZELLERBACH

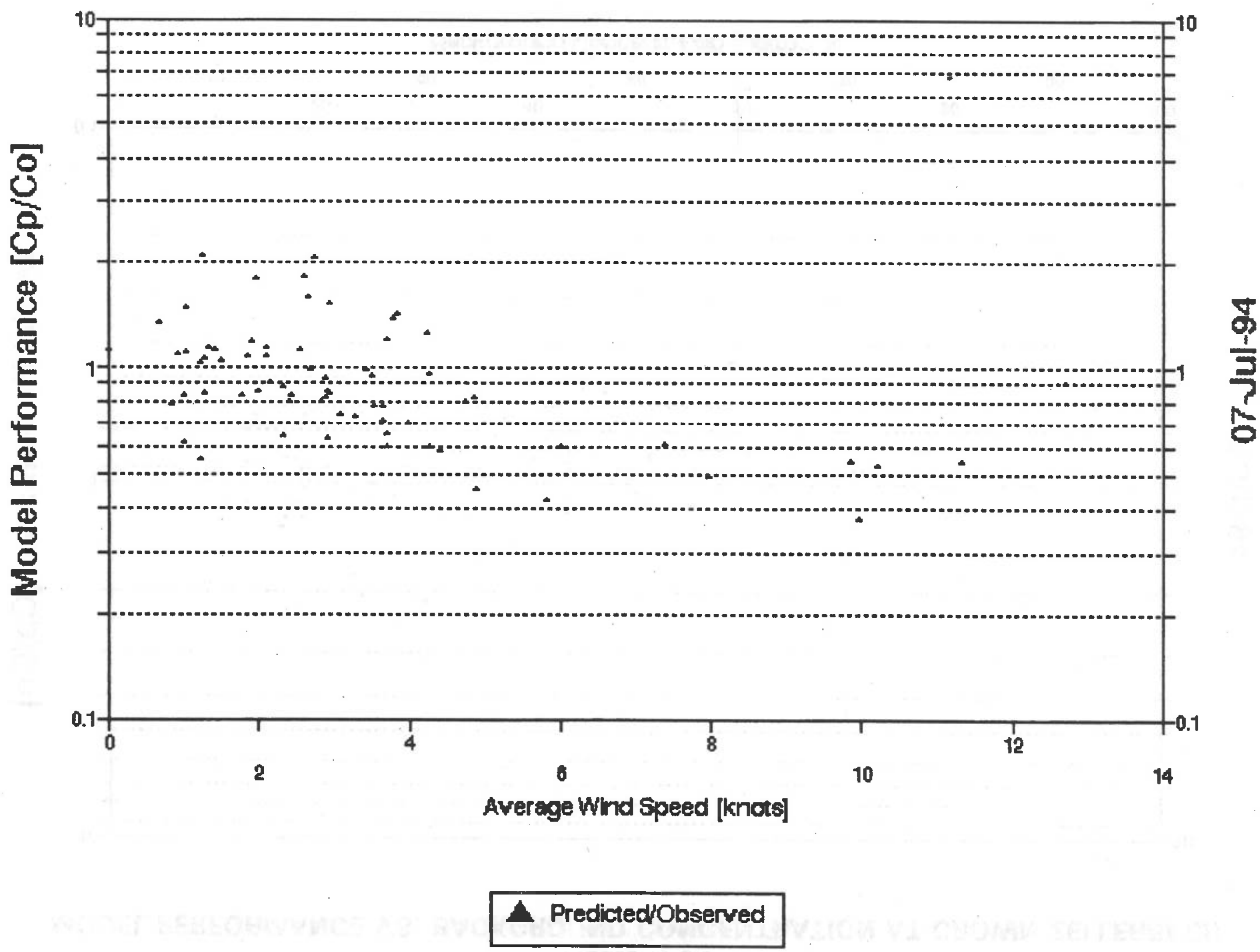


Figure K-98
MODEL PERFORMANCE VS. BACKGROUND CONCENTRATION AT CROWN ZELLERBACH

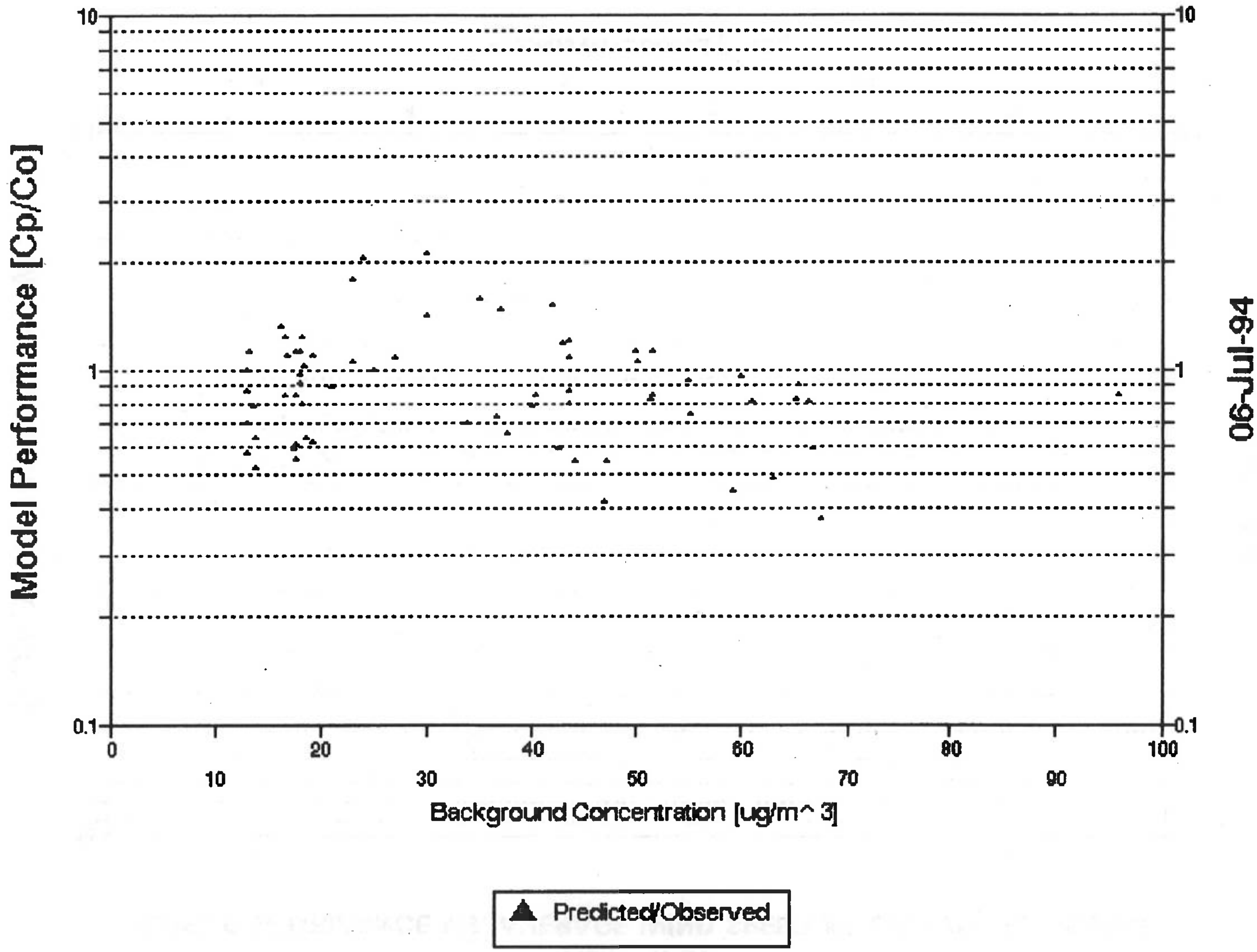


Figure K-99

MODEL PERFORMANCE VS. DAY OF YEAR AT CROWN ZELLERBACH

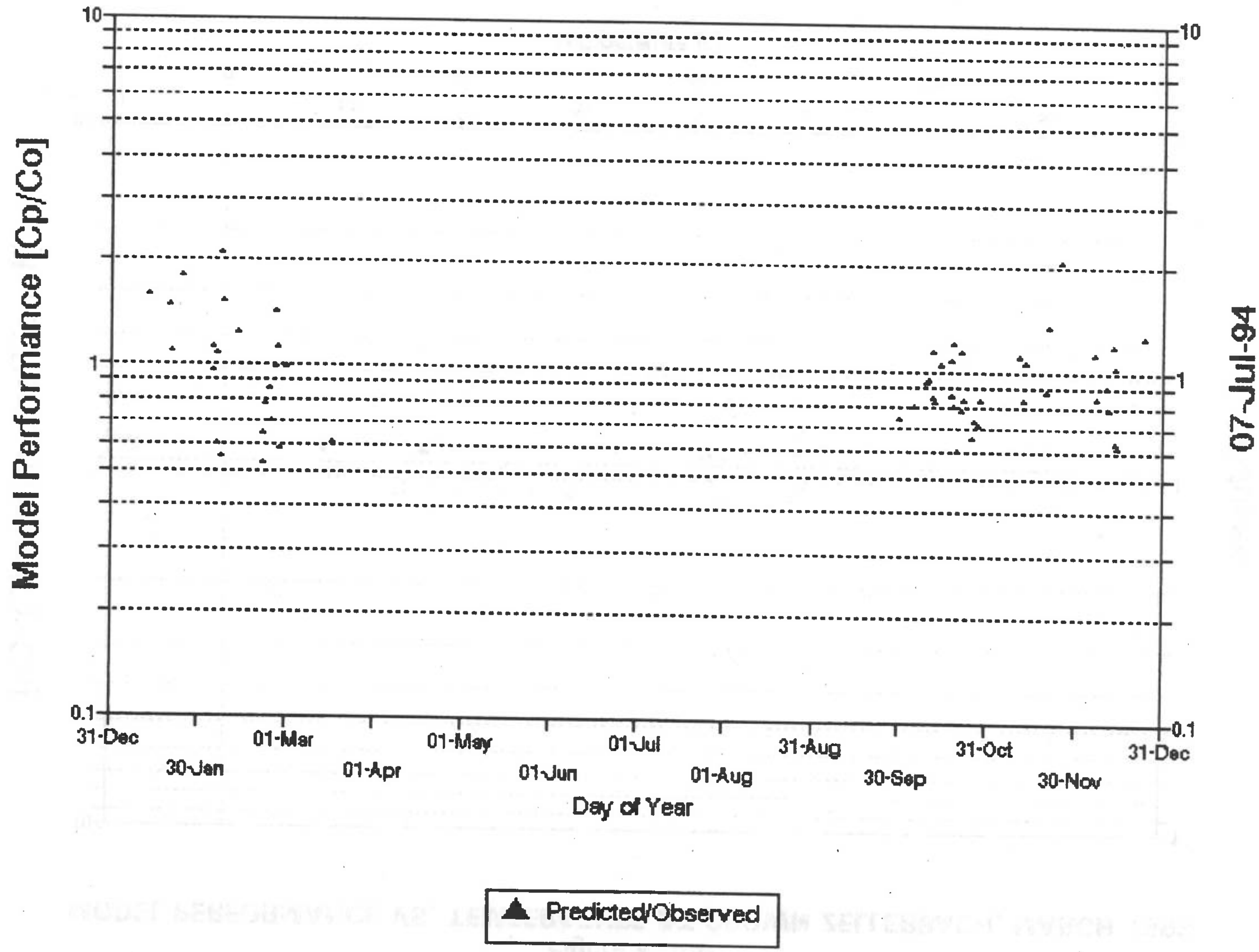


Figure K-100

MODEL PERFORMANCE VS. TEMPERATURE AT CROWN ZELLERBACH, MARCH 1993

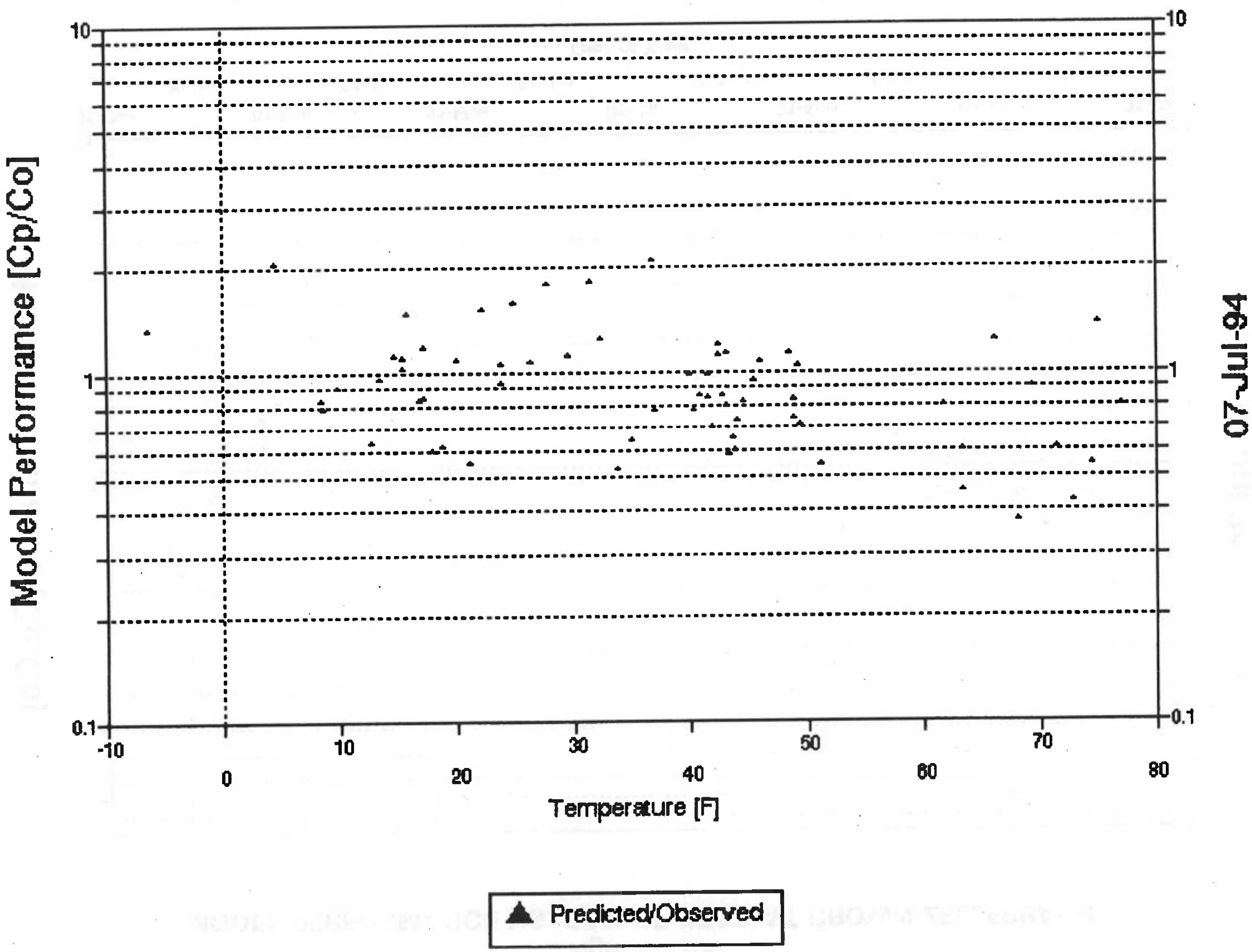


Figure K-101

MODEL PERFORMANCE VS. OBSERVED CONCENTRATION AT CROWN ZELLERBACH

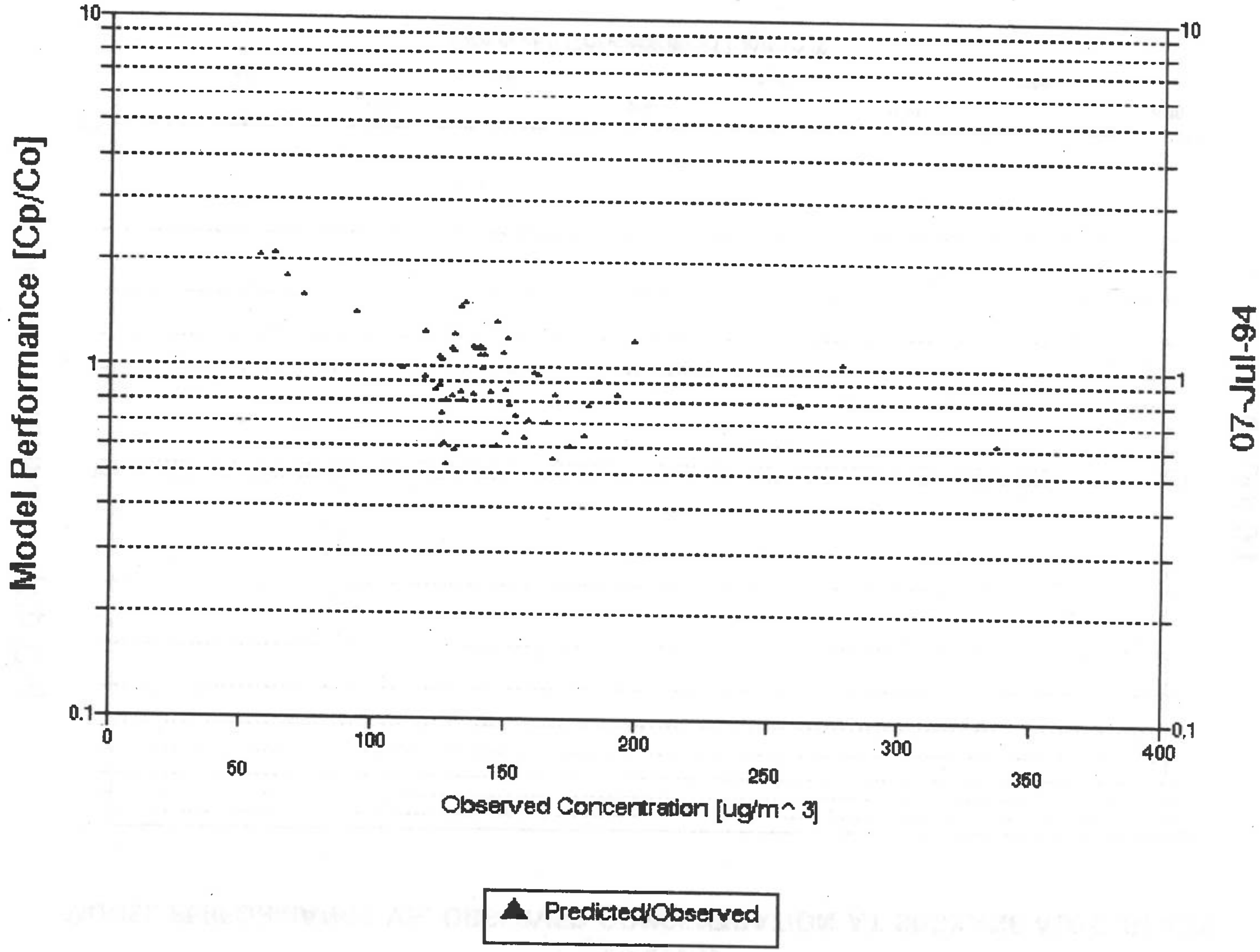


Figure K-102

MODEL PERFORMANCE VS. OBSERVED CONCENTRATION AT SPOKANE AUTO GLASS

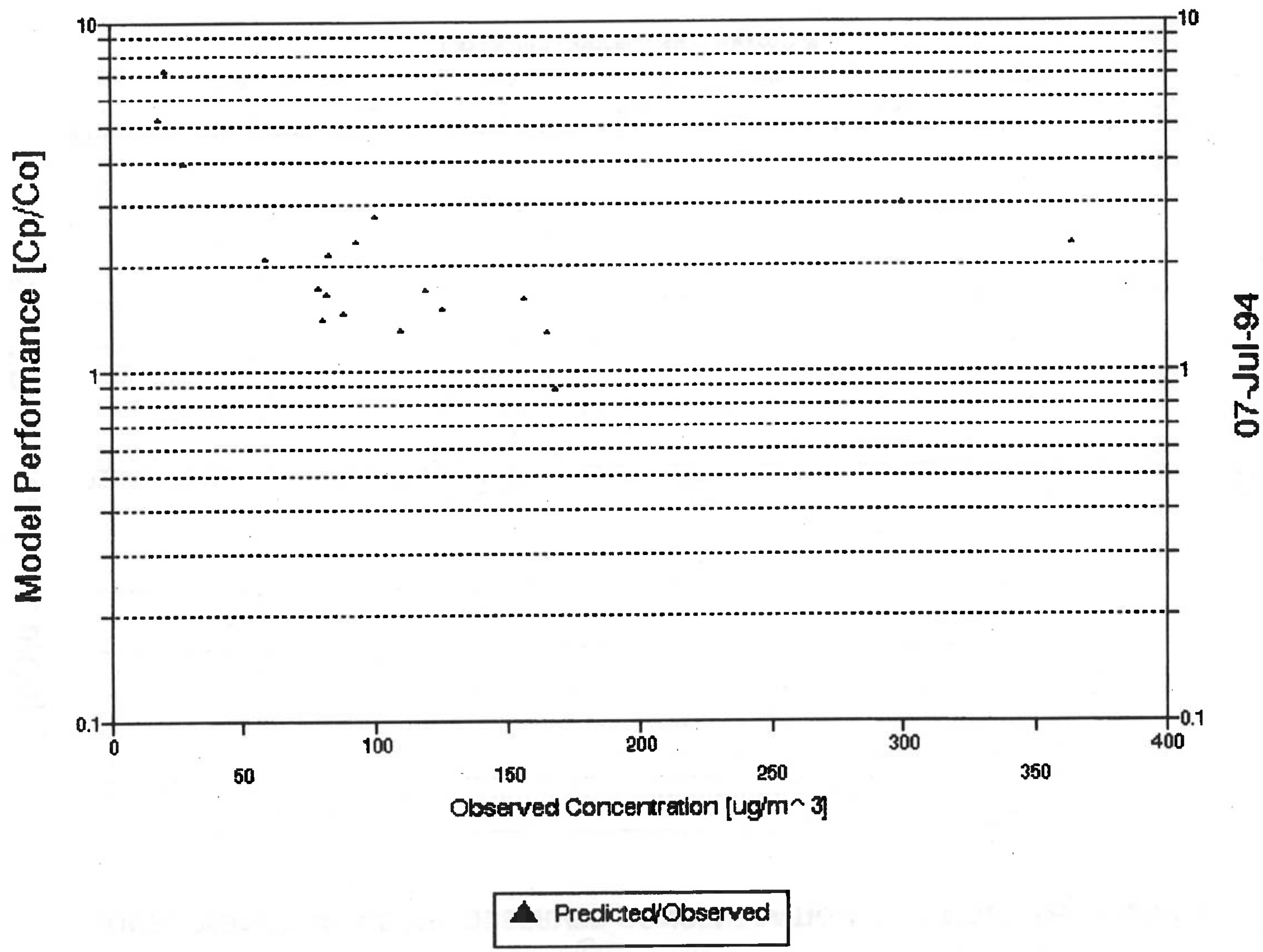


Figure K-103

MODEL PERFORMANCE VS. OBSERVED CONCENTRATION AT COUNTRY HOMES

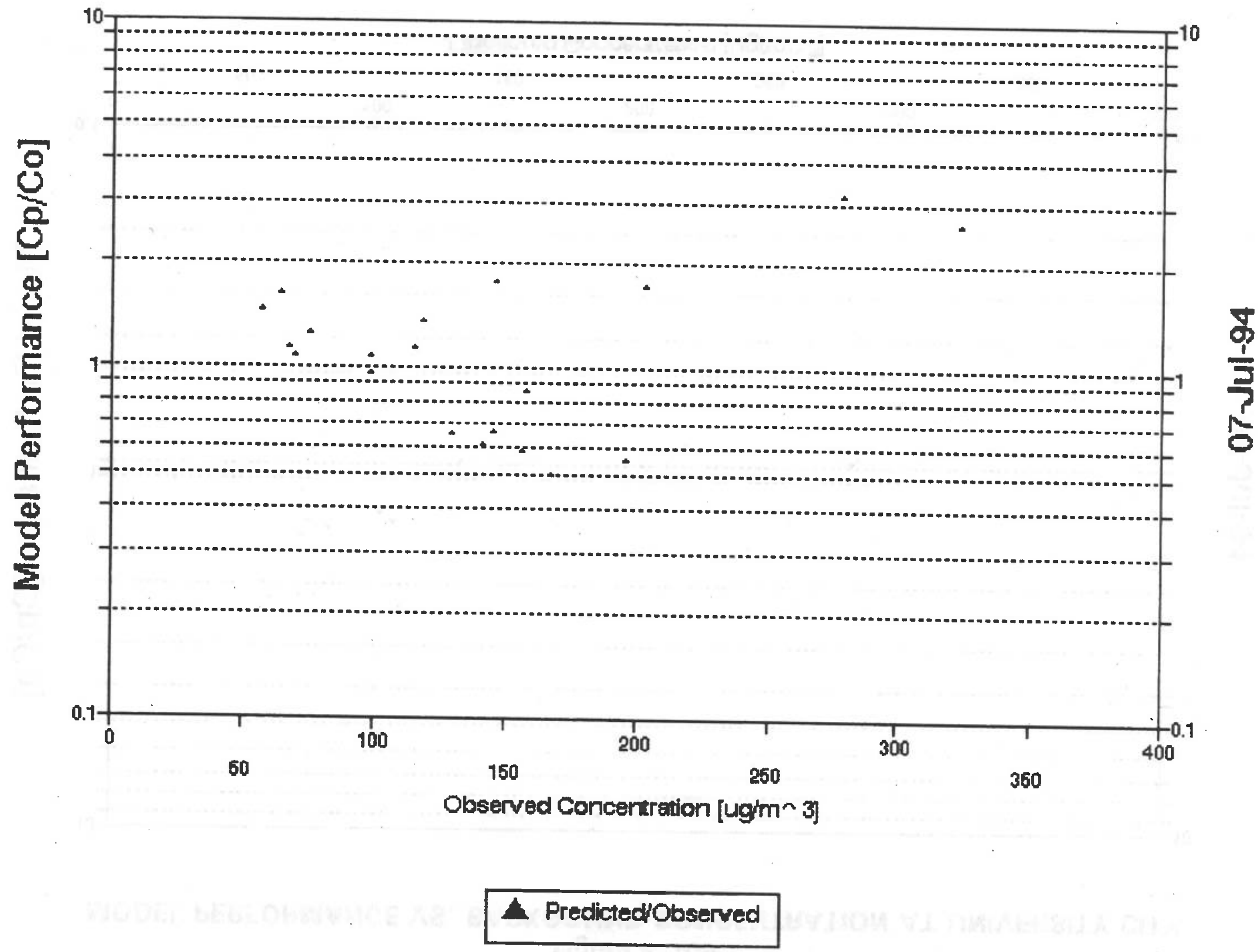


Figure K-104
MODEL PERFORMANCE VS. BACKGOUND CONCENTRATION AT UNIVERSITY CITY

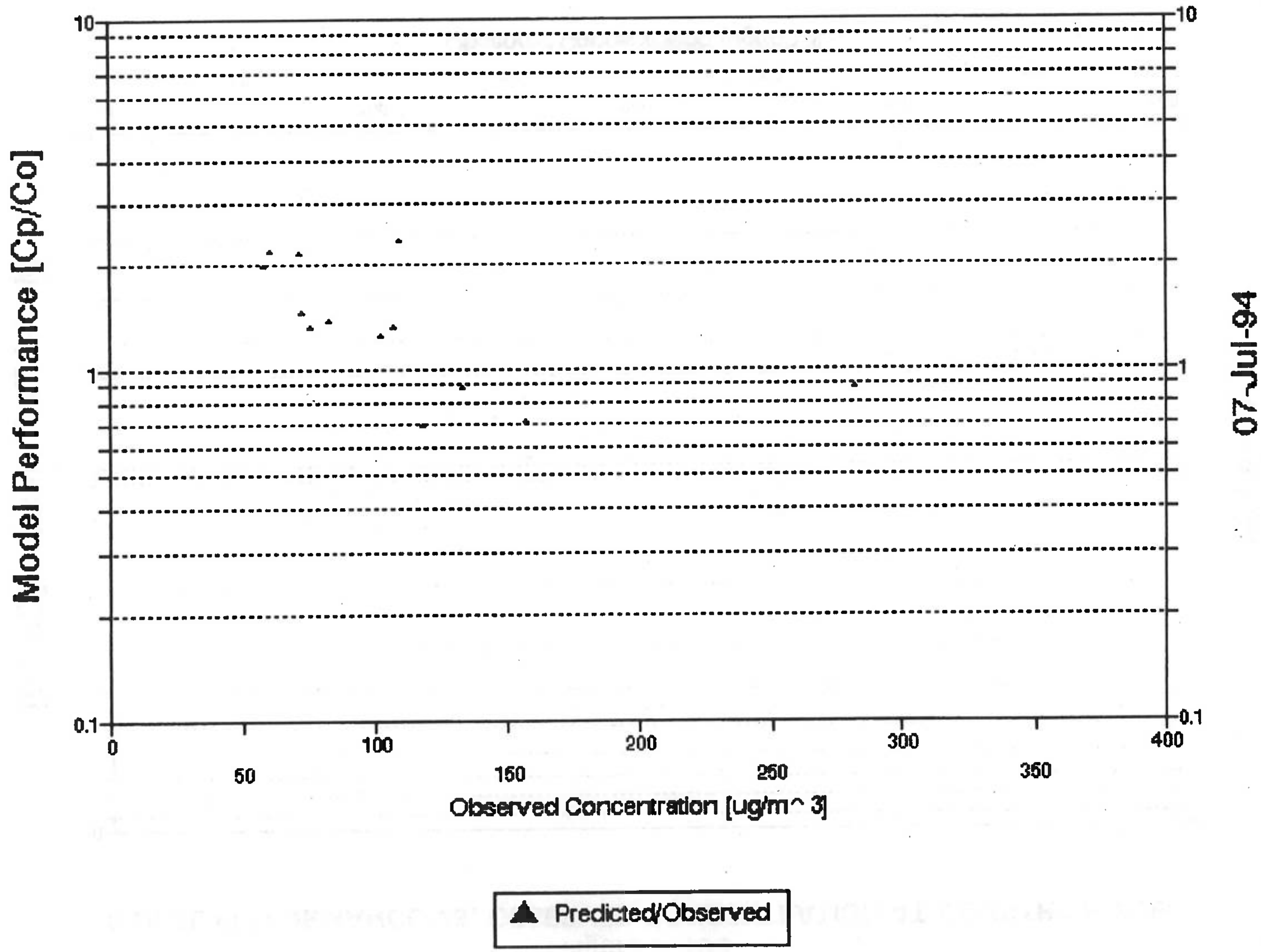


Figure K-105
MODEL PERFORMANCE VS. SNOW DEPTH AT CROWN ZELLERBACH

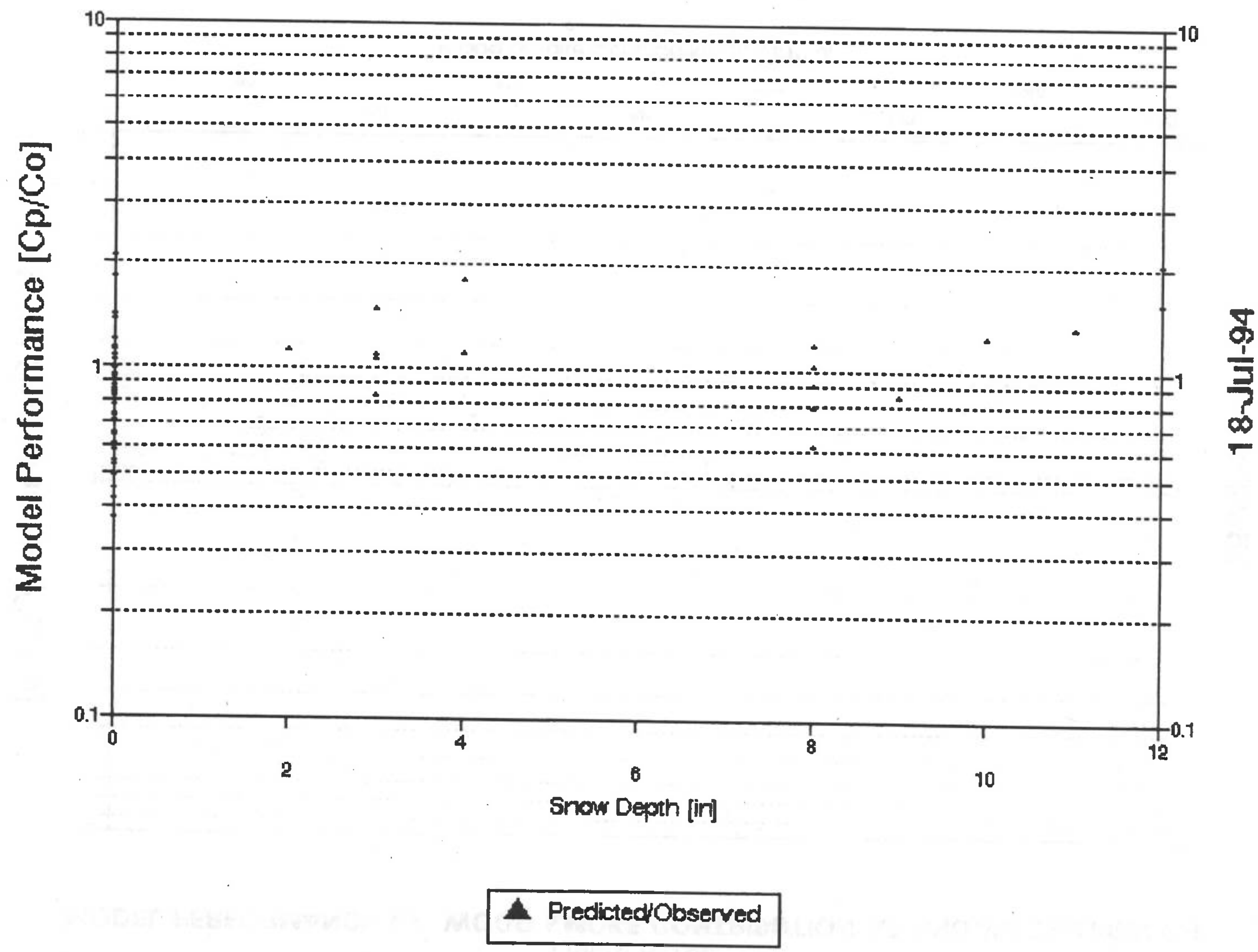


Figure K-106

MODEL PERFORMANCE VS. WOOD SMOKE CONTRIBUTION AT CROWN ZELLERBACH

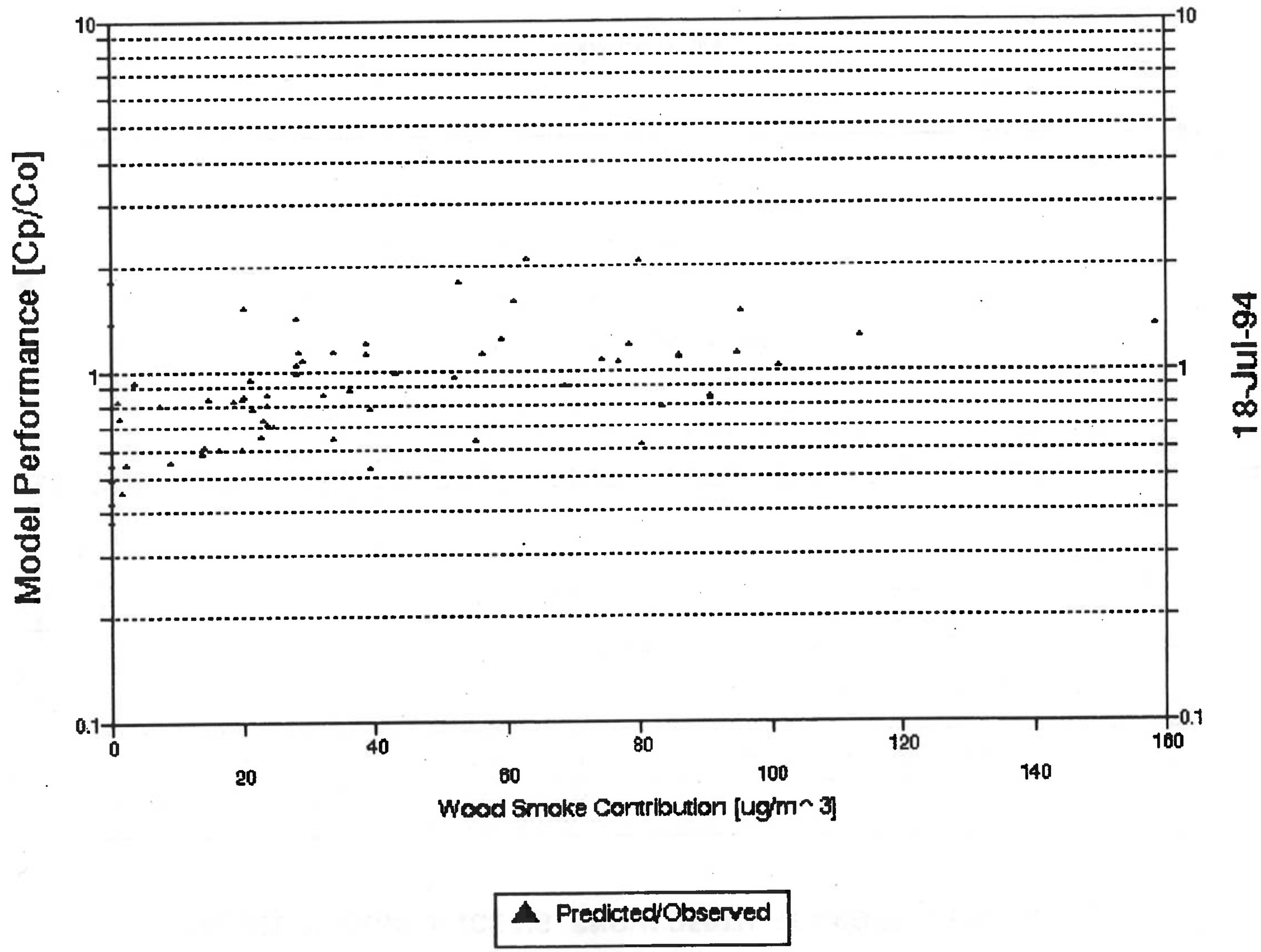


Figure K-107

MODEL PERFORMANCE VS. ROAD DUST CONTRIBUTION AT CROWN ZELLERBACH

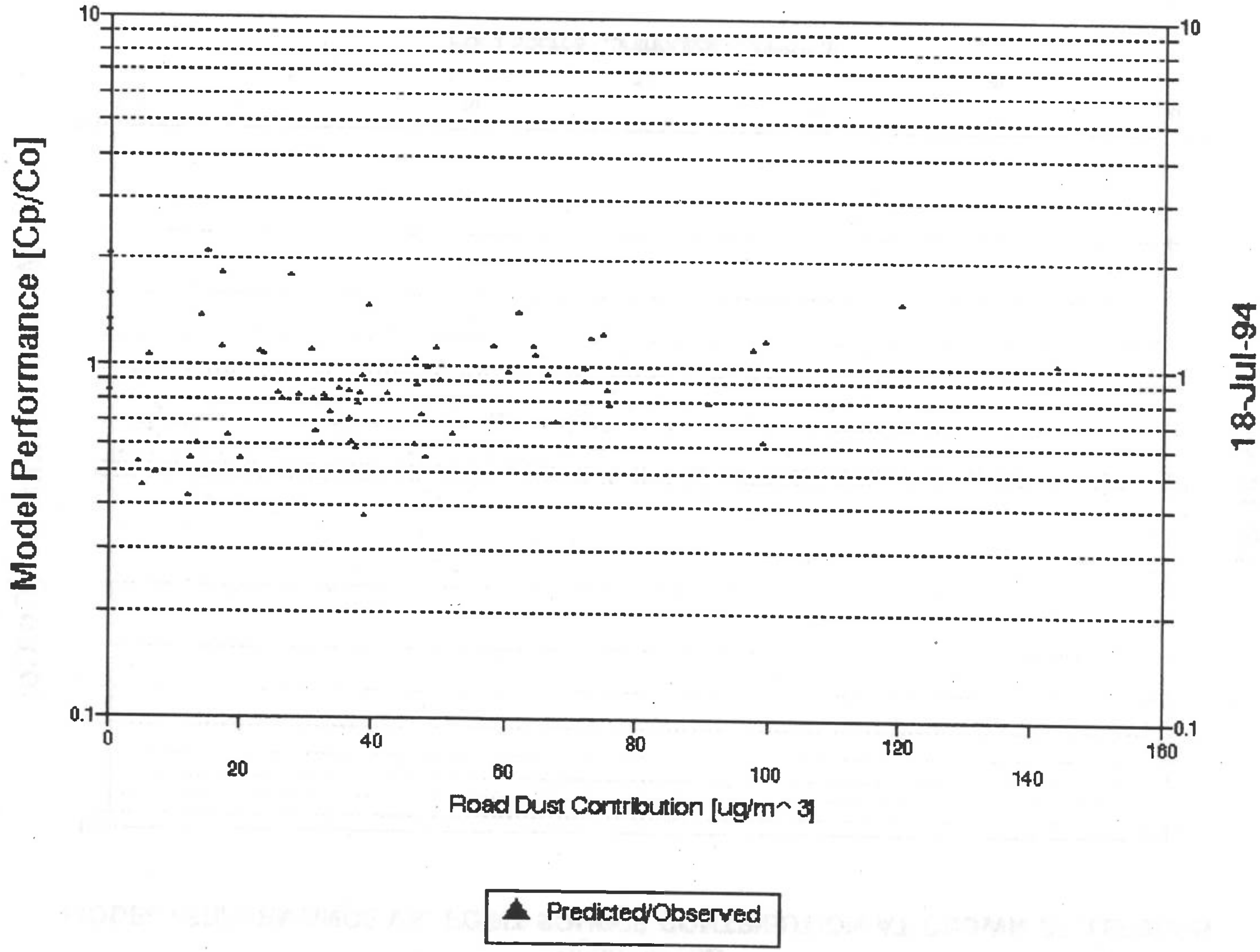


Figure K-108

MODEL PERFORMANCE VS. POINT SOURCE CONTRIBUTION AT CROWN ZELLERBACH

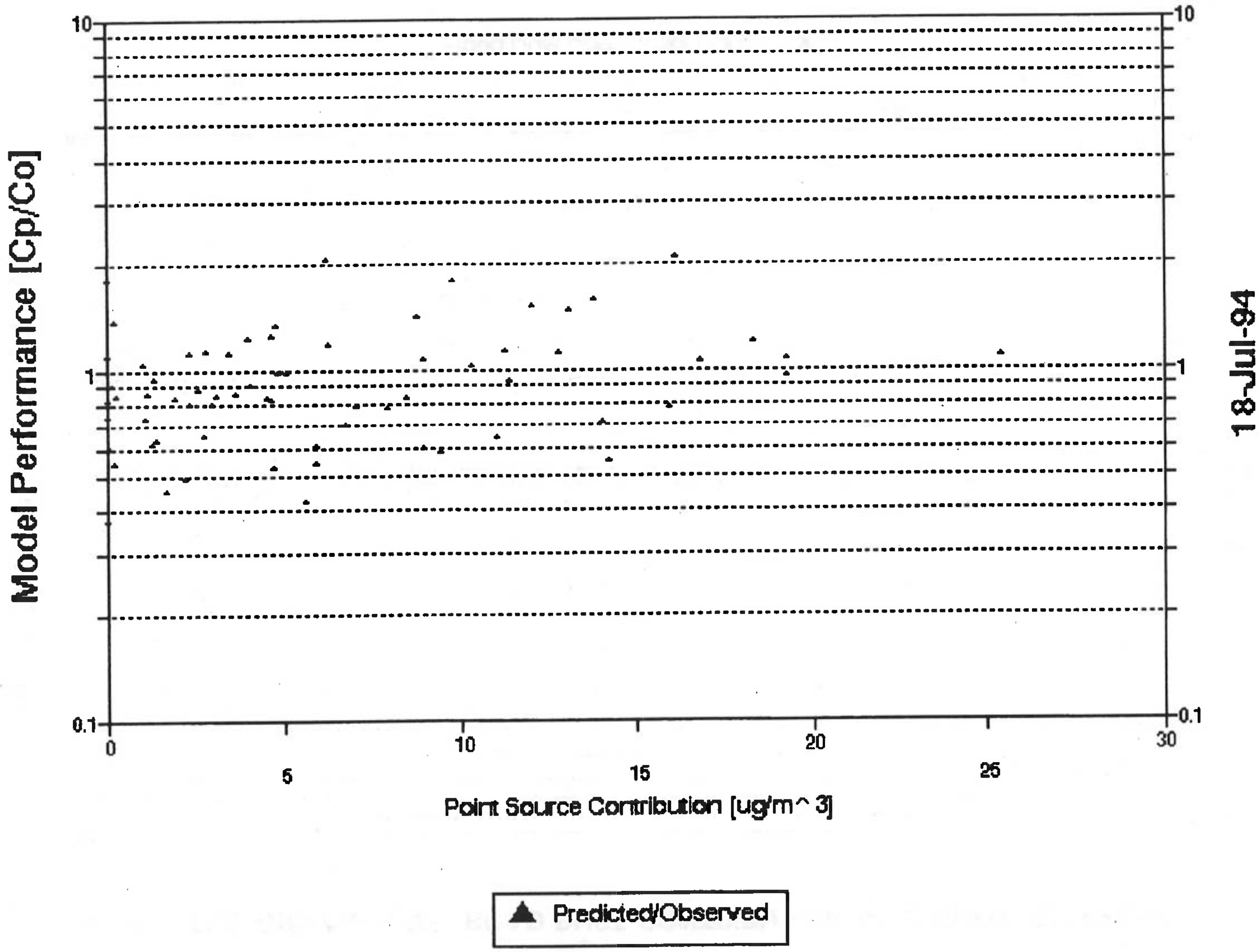


Figure K-109
PRE-1990 24-HOUR AIR QUALITY LEVELS WITHOUT CONTROLS, EXCLUDING WINDBLOWN DUST AND TRACTION MATERIALS

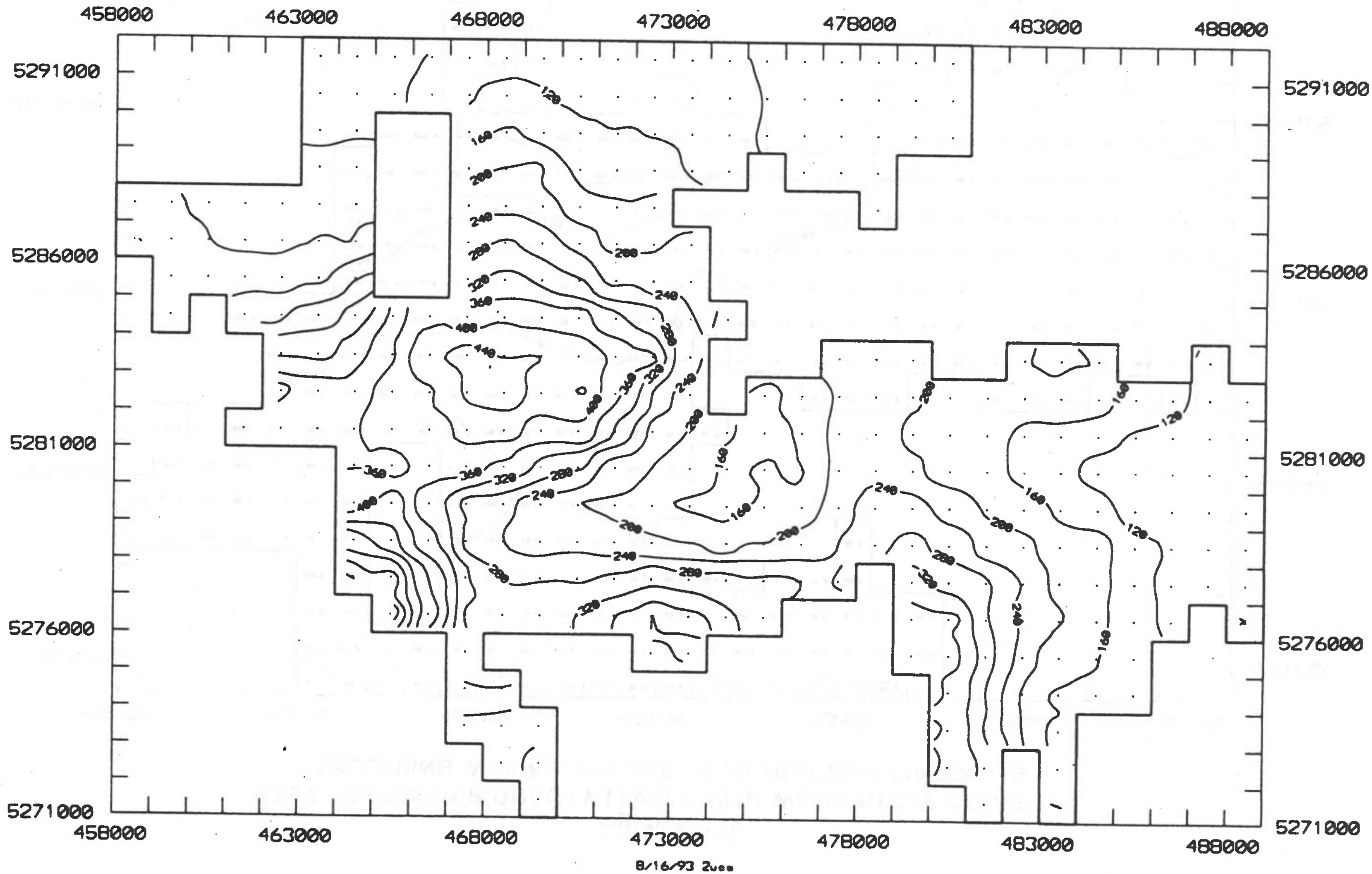
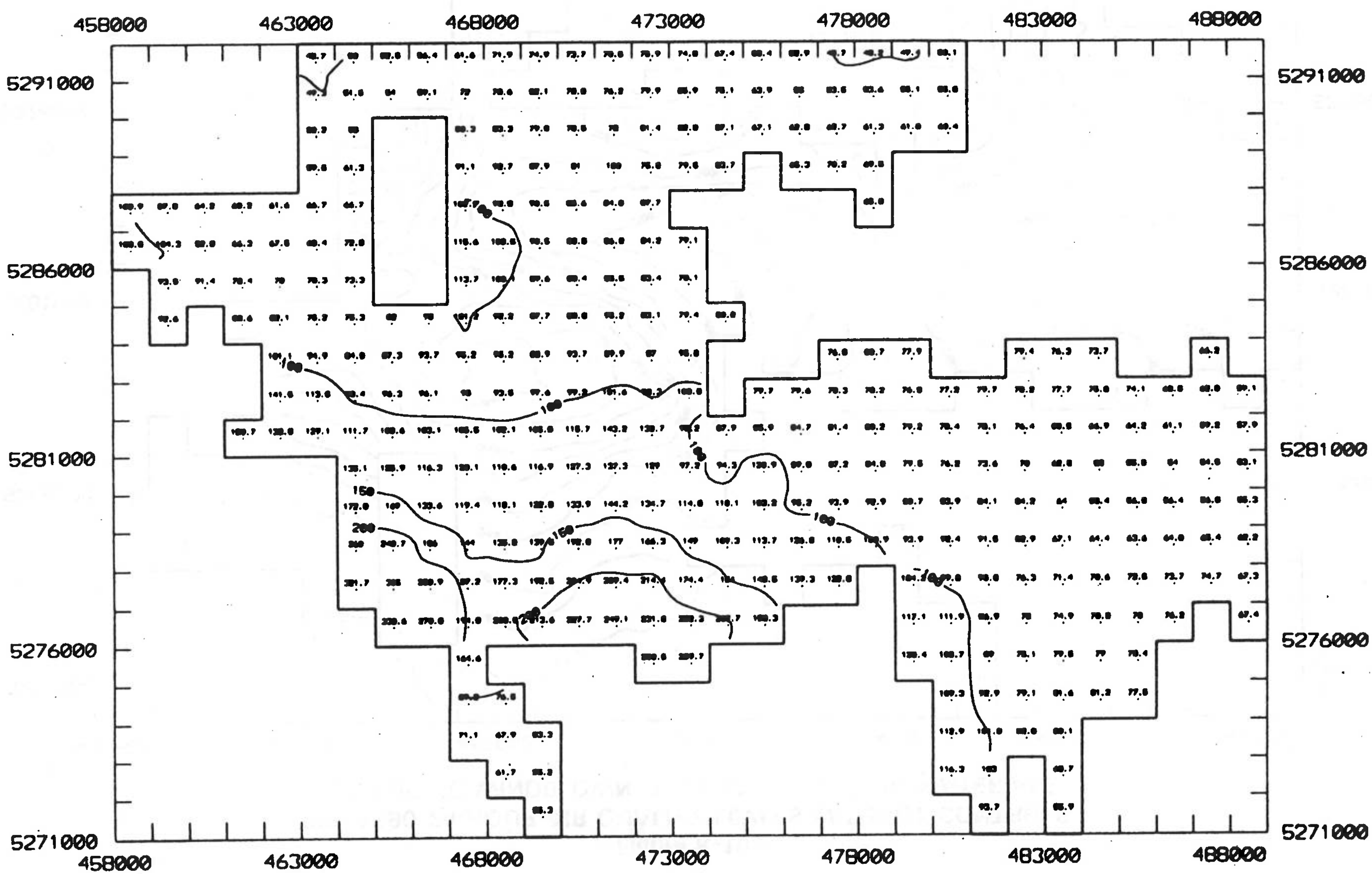


Figure K-110

1997 24-HOUR AIR QUALITY LEVELS WITH WOOD STOVE CONTROLS, EXCLUDING WINDBLOWN DUST AND TRACTION MATERIALS



8/3/93

Figure K-111
1997 UNPAVED ROAD EMISSIONS

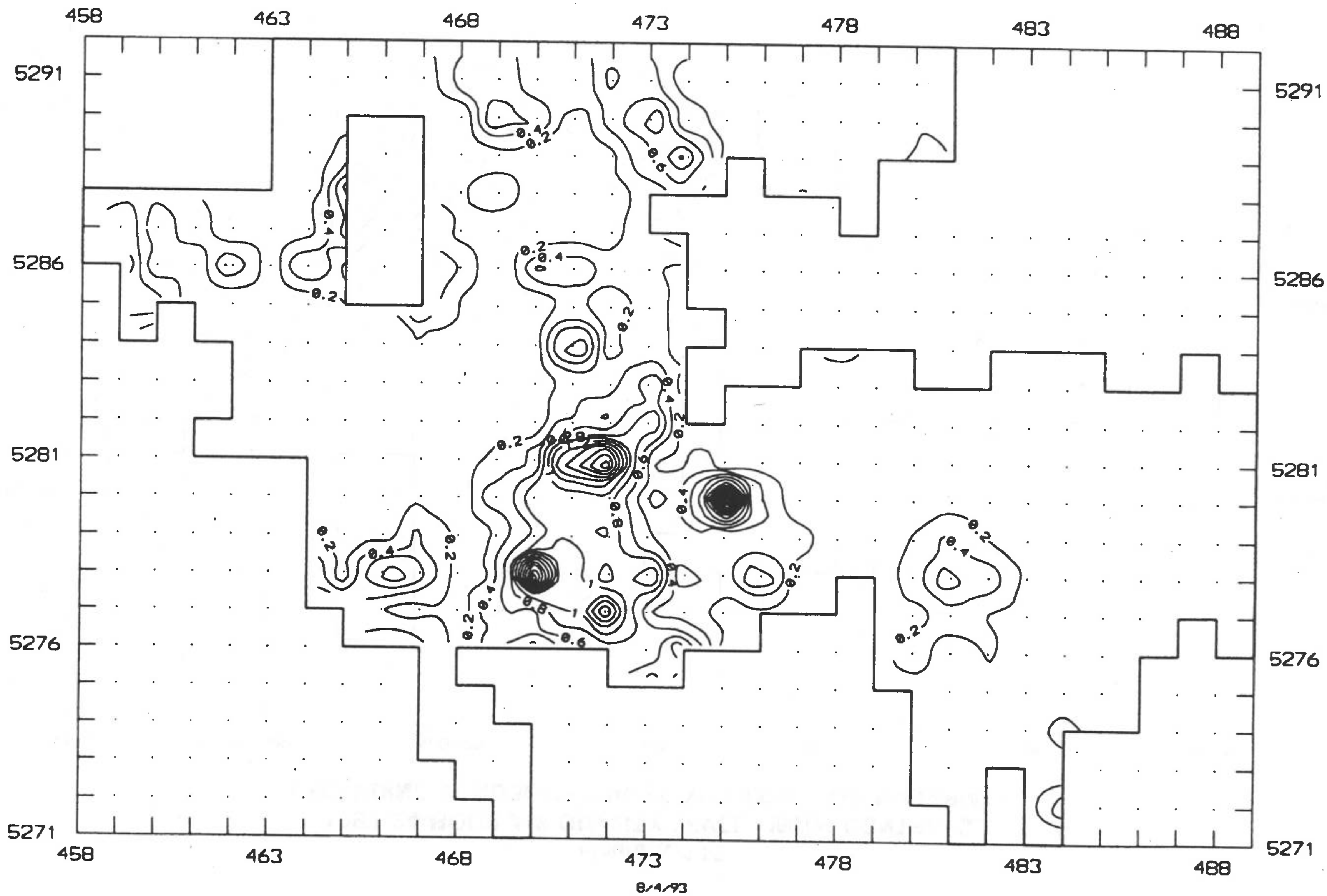


Figure K-112
1997 24-HOUR AIR QUALITY LEVELS WITH CONTROLS, EXCLUDING WINDBLOWN DUST AND TRACTION MATERIALS

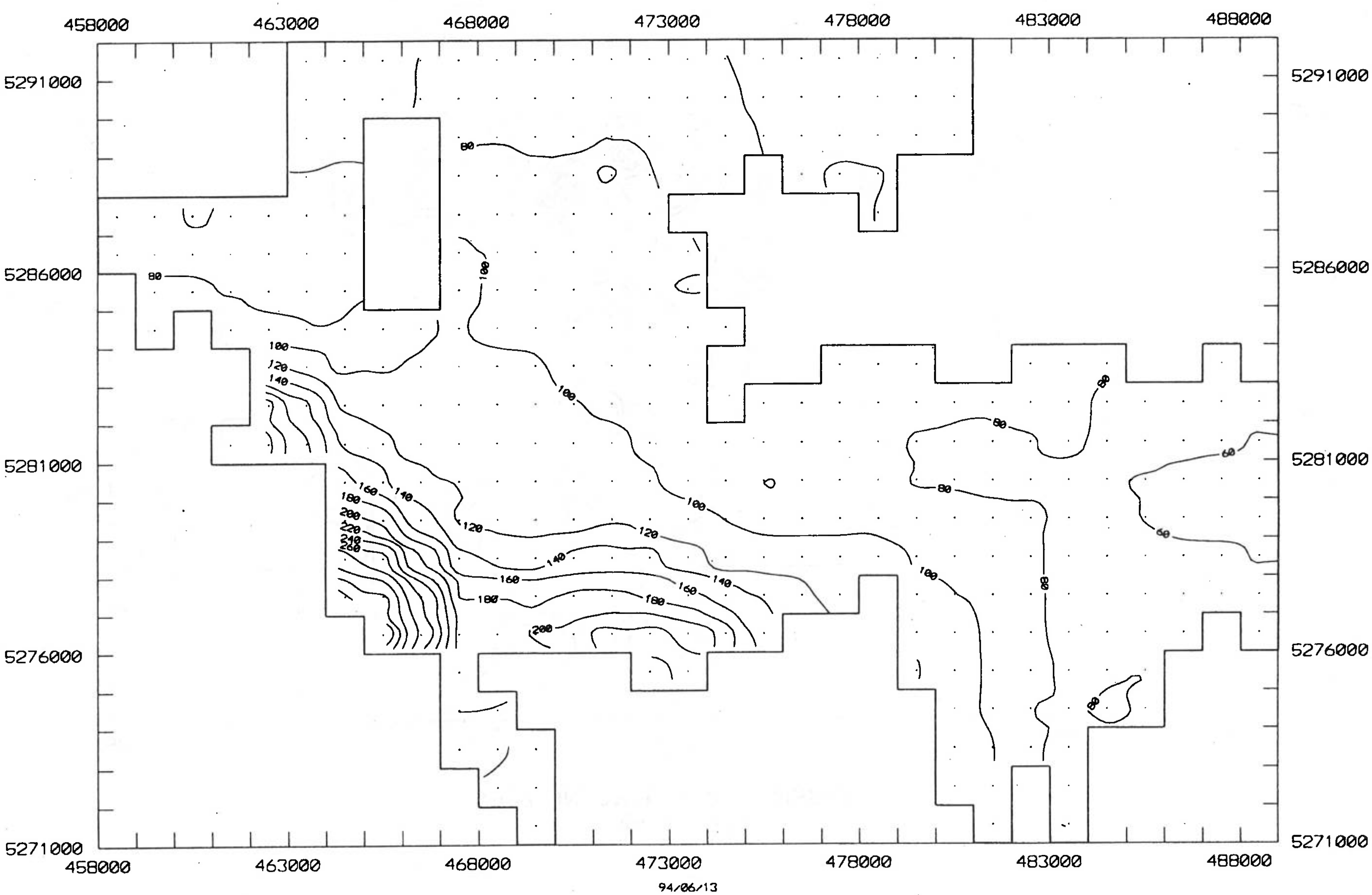


Figure K-113
1997 24-HOUR AIR QUALITY LEVELS WITH TRACTION MATERIALS BUT WITHOUT CONTROLS, EXCLUDING WINDBLOWN DUST

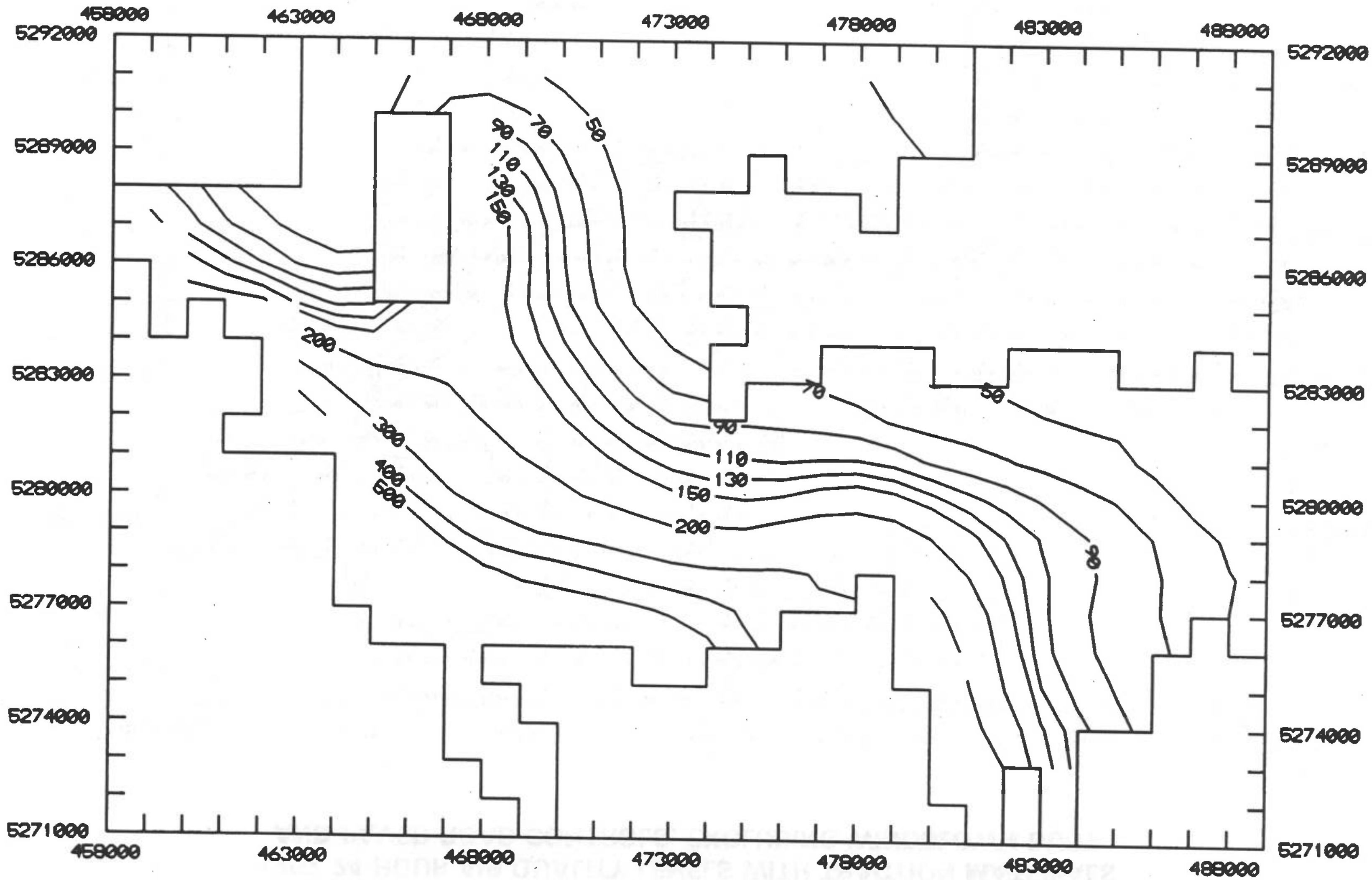


Figure K-114
1997 24-HOUR AIR QUALITY LEVELS WITH TRACTION MATERIALS AND PAVED ROAD CONTROLS, EXCLUDING WINDBLOWN DUST

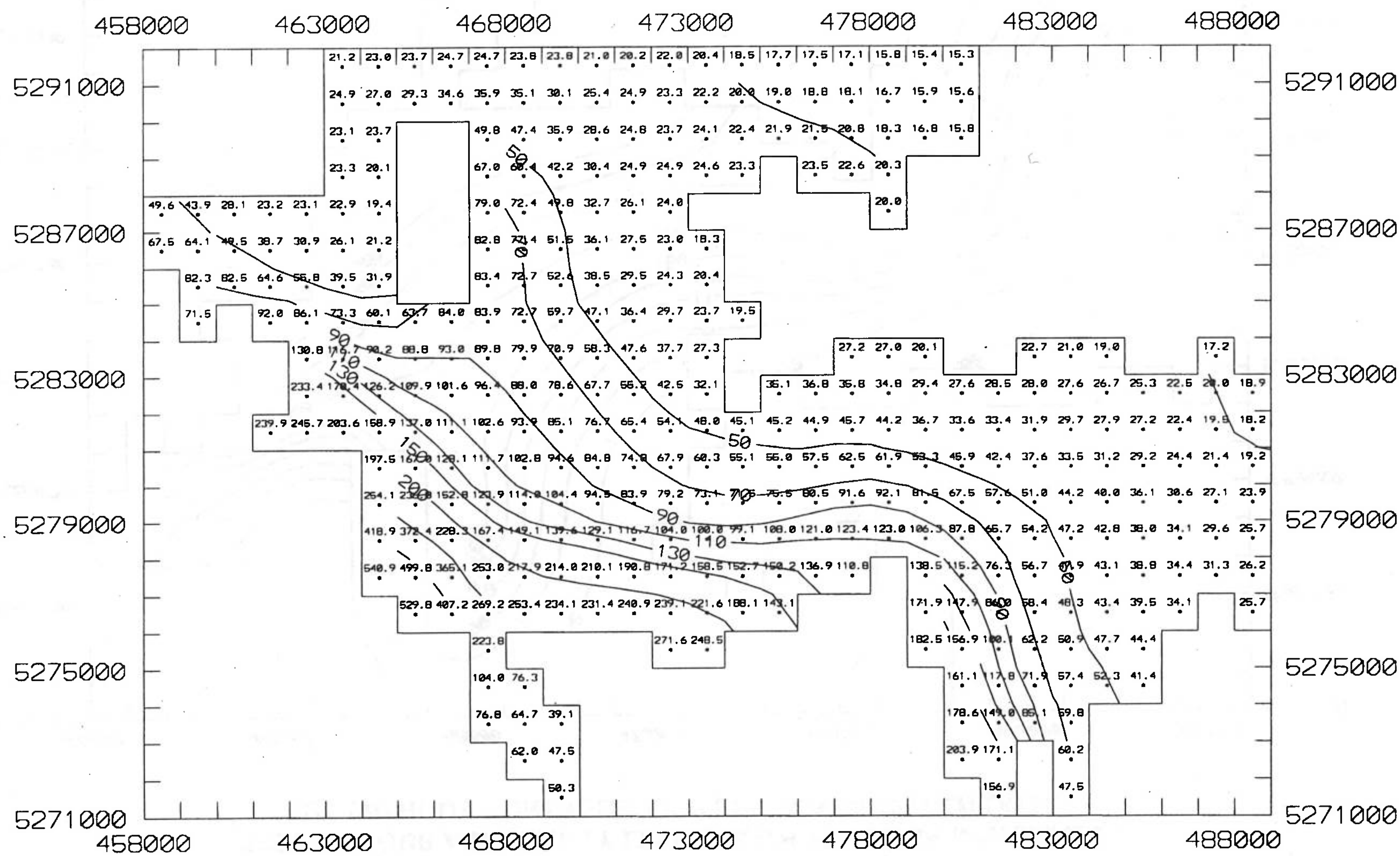


Figure K-115
1997 24-HOUR AIR QUALITY LEVELS WITH TRACTION MATERIALS AND PAVED ROAD AND WOOD STOVE CONTROLS, EXCLUDING WINDBLOWN DUST

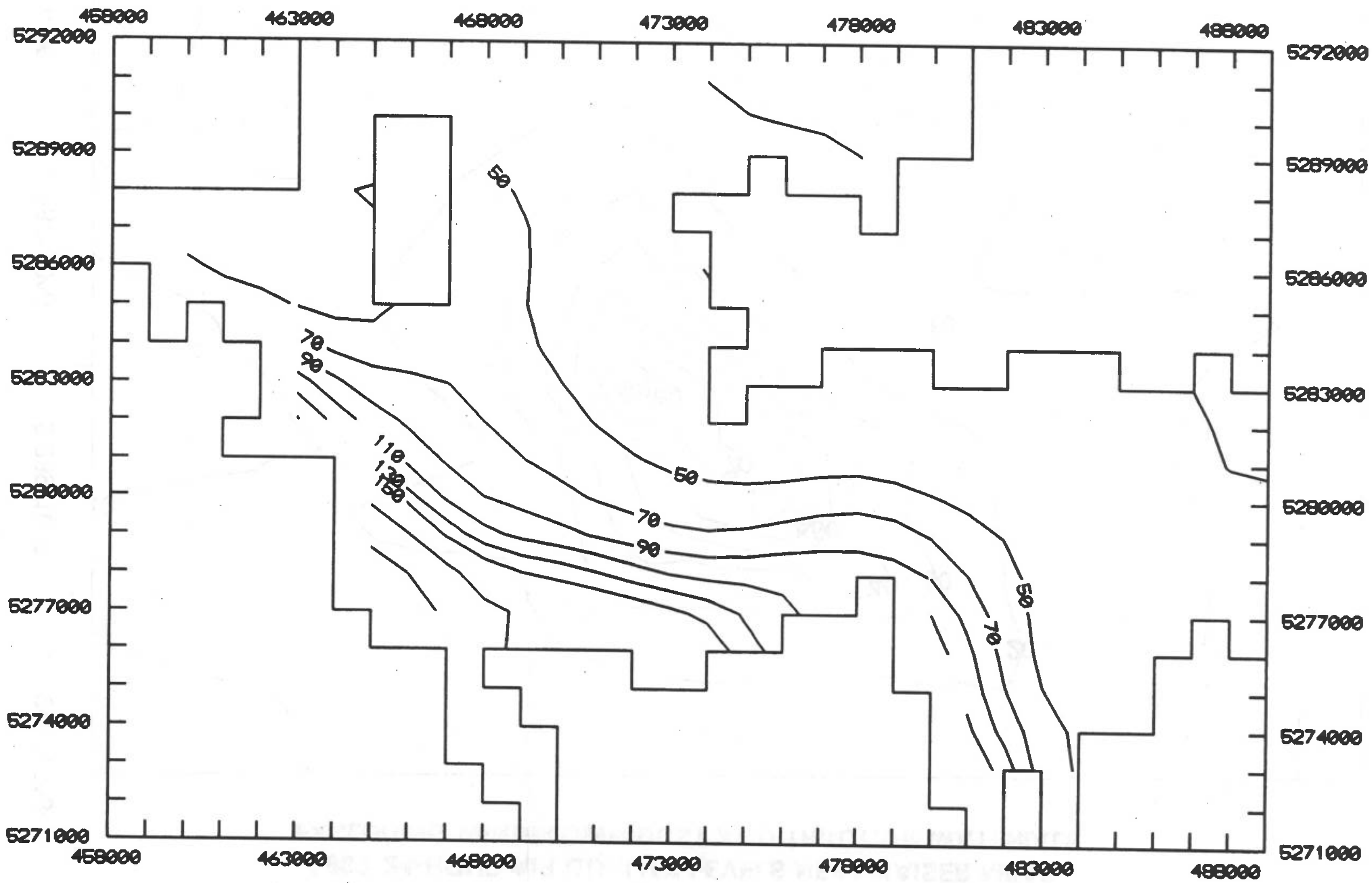


Figure K-116
1997 24-HOUR AIR QUALITY LEVELS NEAR KAISER MEAD, EXCLUDING WINDBLOWN DUST AND TRACTION MATERIALS

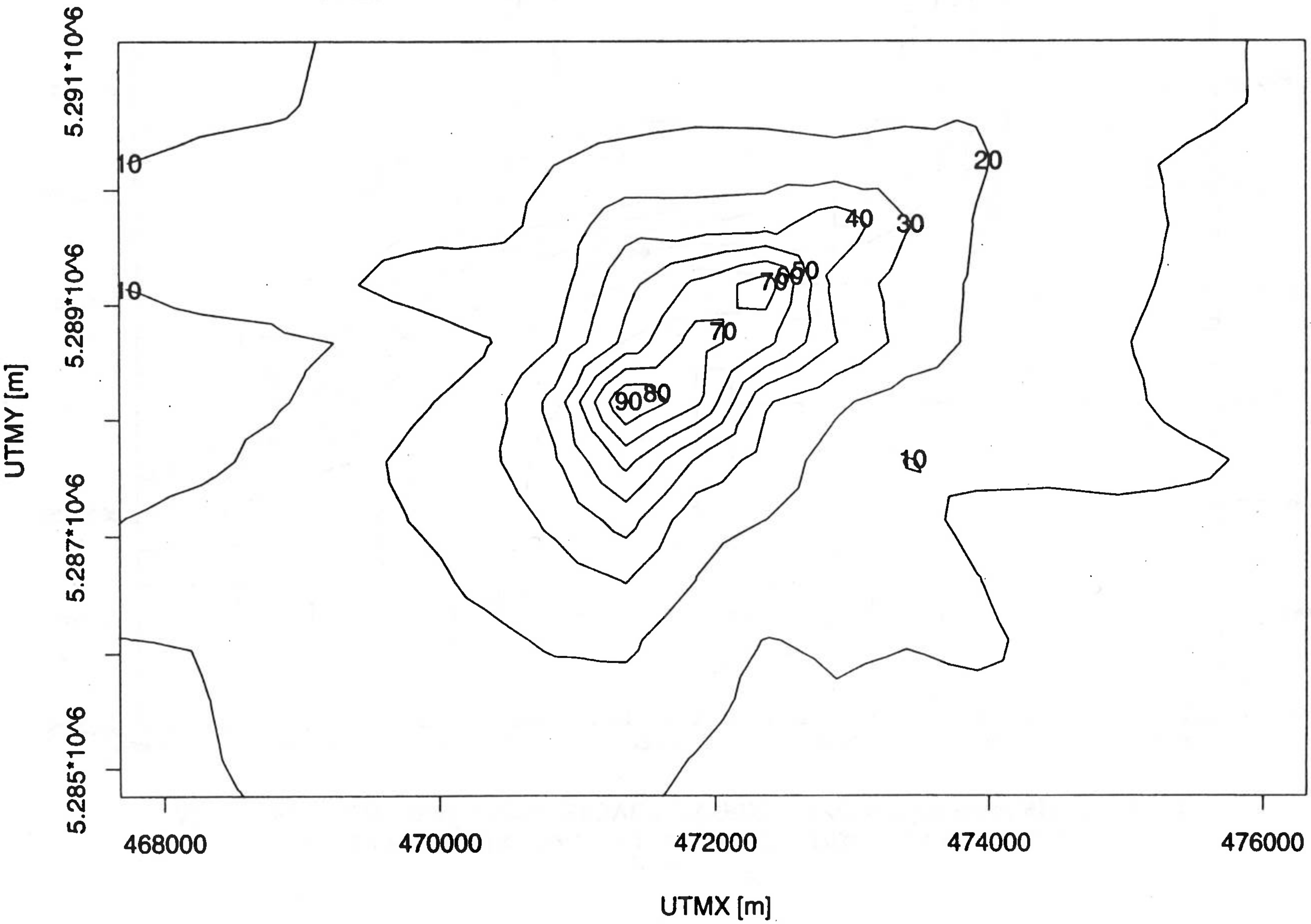


Figure K-117
1997 24-HOUR AIR QUALITY LEVELS NEAR KAISER TRENTWOOD EXCLUDING WINDBLOWN DUST AND TRACTION MATERIALS

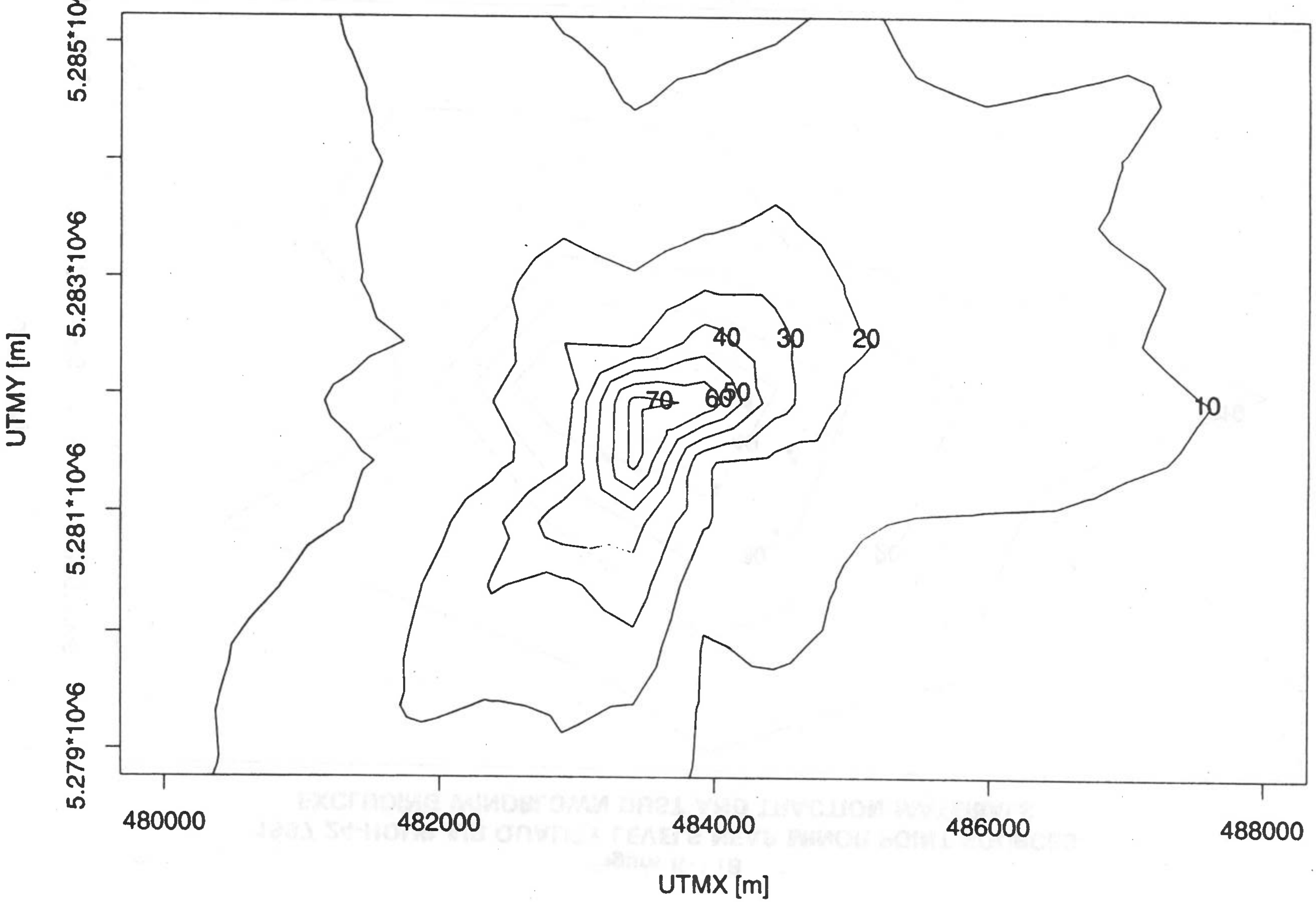


Figure K-118
1997 24-HOUR AIR QUALITY LEVELS NEAR MINOR POINT SOURCES EXCLUDING WINDBLOWN DUST AND TRACTION MATERIALS

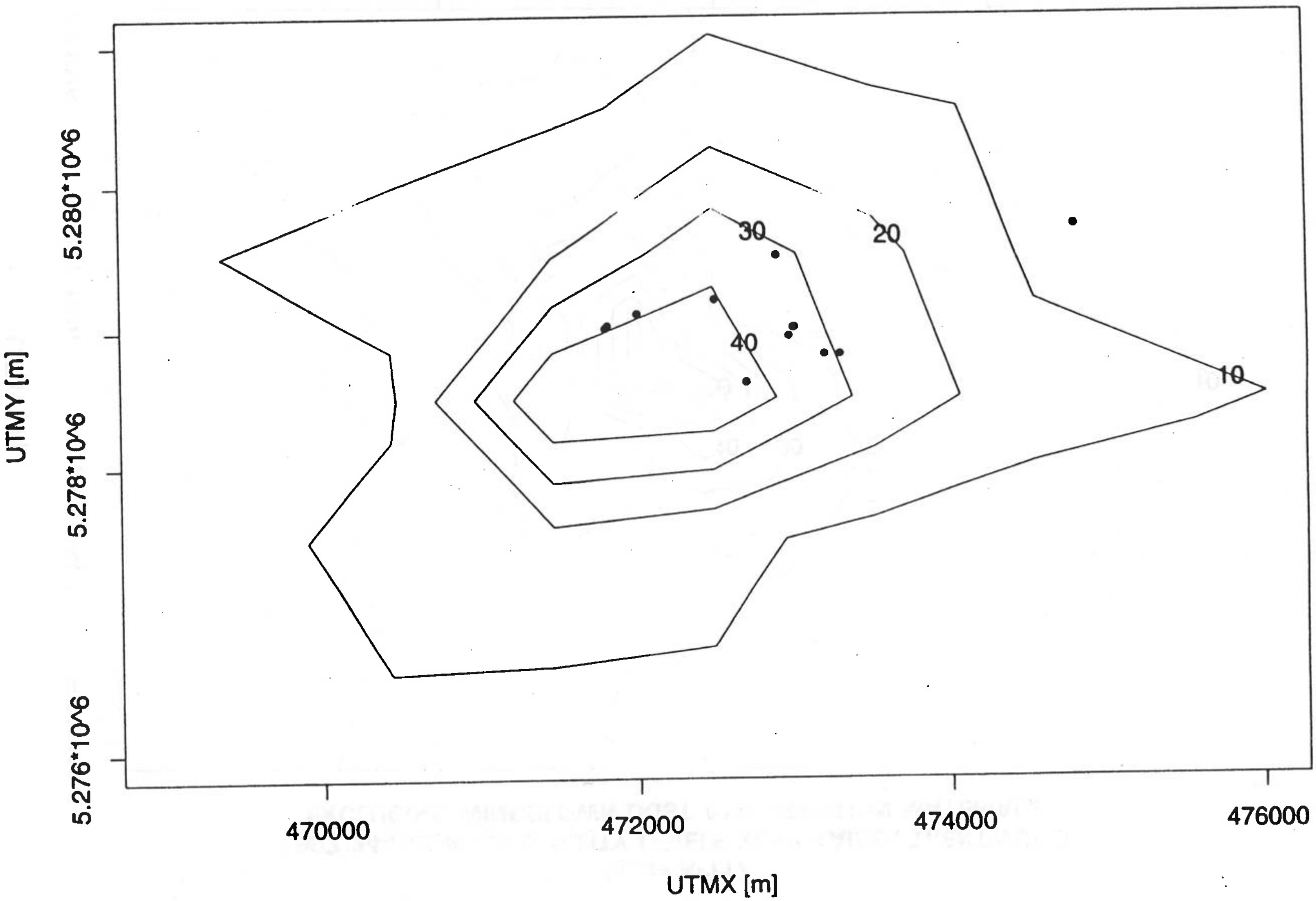


Table K-1
DURATION OF CALMS

BEGINNING DATE	CONSECUTIVE HOURS IN EACH PERIOD OF CALM	TOTAL HOURS OF CALM	TOTAL HOURS
12 NOV 85	1, 6, 4, 3, 15, 1, 5, 2, 6, 4, 2, 1, 3	53	84
22 NOV 85	1, 18, 2	21	36
26 NOV 85	3, 1, 1, 1, 1, 1, 2, 5	15	36
9 DEC 85	3, 5, 2, 11, 1, 1, 1	24	36
12 DEC 85	3, 3, 5, 4, 1, 8, 4, 2, 1, 6, 3, 2, 2, 6, 4, 9, 1, 2, 2, 8, 1, 4, 3	84	132
13 JAN 86	2, 1, 1, 1, 1, 1, 5	12	36
25 JAN 86	1, 10, 3, 2, 1, 3, 2, 1	23	36
2 FEB 86	4, 13, 1, 1, 8, 2, 2, 1, 2, 1, 2	37	60
26 FEB 86	1, 1, 1, 1, 1, 7, 1, 1, 1, 1, 3, 3	22	60
2 MAR 86	1, 3, 3, 1, 1, 1, 1, 1	12	36
6 JUN 86	1, 1, 2, 4, 1, 1	10	36
27 AUG 86	1, 1, 6	8	36
12 OCT 86	3, 1, 7, 1, 1, 2, 3, 2	20	60
15 OCT 86	1, 10, 1, 3, 2	17	36
19 OCT 86	6, 1, 1, 1, 2, 6, 1, 1, 2, 2, 5, 2	30	60
22 OCT 86	3, 14, 5, 1, 6, 2, 1, 1, 2	35	60
8 DEC 86	1, 32	33	36
7 JAN 87	1, 10, 1, 1, 4, 1	18	35
20 JAN 87	1, 12, 1, 10, 2, 11, 2, 3, 3	45	59
7 FEB 87	2, 5, 9, 2, 1, 1, 3	23	35
22 FEB 87	2, 10	12	35
17 MAY 87	2	2	35
1 SEP 87	1, 7	8	35
24 SEP 87	1, 1, 1, 1	4	35
25 SEP 87	1, 1, 1, 1	4	36
1 OCT 87	1	1	35
11 OCT 87	2, 2, 1, 2, 1, 2, 4, 1	15	59
19 OCT 87	1, 4, 1, 3, 1, 11, 1, 1, 1, 3, 2, 2, 2, 1	34	107

BEGINNING DATE	CONSECUTIVE HOURS IN EACH PERIOD OF CALM	TOTAL HOURS OF CALM	TOTAL HOURS
26 OCT 87	4, 2, 6, 4, 4, 1, 1, 4	26	107
25 DEC 87	13, 2, 9	24	35
22 FEB 88	1, 1, 2, 1, 2, 2, 3, 1, 4, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 5, 1, 1, 1, 2	39	132
28 FEB 88	1, 1, 1, 2, 1, 1, 1	8	36
17 MAR 88	1, 3, 1, 1, 1	7	36
11 MAY 88	3, 2, 1	6	36
15 JUN 88	4, 1, 2, 5, 2, 1	15	36
28 AUG 88	1	1	60
31 AUG 88	1, 2	3	36
5 SEP 88	4	4	36
5 OCT 88	2, 2, 1, 1, 2, 1, 1	10	36
9 OCT 88	1, 1, 2, 4, 1, 1, 3	13	36
14 DEC 88	7, 3, 1, 1	12	36
5 FEB 89	1, 3, 1, 1, 1, 2, 3, 1, 1, 2, 2, 4, 1, 1, 2, 2, 4, 1, 1, 2, 6, 6, 5, 9, 1, 1, 6, 1	71	132
13 FEB 89	1, 2, 9, 2	14	36
24 SEP 89	1, 1, 2	4	36
4 OCT 89	1, 1, 1, 1, 3, 2, 2	11	36
21 NOV 89	2, 1, 1, 2, 1, 3, 2	12	36

Table K-2
UNPAVED ROAD SURFACE TYPES

CITY CODES*	ROAD SURFACE TYPES
d	Dirt
dg	Dirt Graded
dgo	Dirt Graded Oiled
di	Dirt Improved
du	Dirt Unimproved
g	Gravel
g--	Gravel NEC
gg	Gravel Graded
ggo	Gravel Graded Oiled
gi	Gravel Improved
go	Gravel Oiled
gu	Gravel Unimproved
n	Native
ng	Native Graded
ng.5	Native Graded on 1/2
ngo	Native Graded Oiled
ni	Native Improved
nio	Native Improved Oiled
nu	Native Unimproved
p (SRTC Code)	Paved
u (SRTC Code)	Unpaved
ug	Unimproved Graded
ugo	Unimproved Graded Oiled
ung	Unimproved Native Graded

* except where indicated otherwise

Table K-3
SILT LOADING TEST RESULTS

Test	Location	Area	Silt Loading
1	Wall Street	40 m x 3 m	.0458
2	Country Homes Blvd (W)	16 m x 6 m	.0042
3	(Residential)	10 m x 6 m	1.1217
4	Country Homes Blvd (E)	14 m x 6 m	.0369
5	Freya Street	40 m x 3 m	.0442
6	Olive Street	10 m x 6 m	.0083

Table K-4
Analysis of Modelling Results When Model Performance Was Outside the Range 0.7 to 1.3

Date	Original Cp/Co	Modified Cp/Co	Other Stations	Comments
23 Nov 85	1.33	1.33		Close enough
27 Nov 85	2.06	2.06	CZp=117;CHp=96;UCp=117 CZo=57;CHo=76;UCo=133	Ave(p)=110 Ave(o)=133;(Cp/Co)ave=1.24
13 Dec 85	0.52	0.91		Added 4*rd to account for traction material. Objective scheme could not handle this very cold, dry period which had 8" of snow on the ground.
14 Dec 85	0.44	0.79		
15 Dec 85	0.68	1.18		
16 Dec 85	0.50	1.02		
17 Dec 85	0.32	0.62		
14 Jan 86	1.58	1.58	CZp=117;CHp=108;UCp=105;AGp=112 CZo=74;CHo=196;UCo=72;AGo=80	Ave(p)=111 Ave(o)=106;(Cp/Co)ave=1.05
26 Jan 86	1.8	1.8	CZp=120;CHp=95;UCp=114;AGp=124 CZo=67;CHo=145;UCo=58;AGo=59	Ave(p)=113 Ave(o)=82;(Cp/Co)ave=1.38
27 Feb 86	0.61	0.99		Multiplied rd by 4 for traction materials
28 Feb 86	0.66	1.12		
03 Mar 86	0.66	0.99		
28 Jun 86	0.42	0.42		Summer winds
21 Jan 87	1.48	1.48	CZp=197;CHp=256;UCp=257;AGp=217 CZo=133;CHo=146;UCo=110;AGo=93	Ave(p)=232 Ave(o)=121;(Cp/Co)ave=1.92 Period had 45 hours of calm (n=60)
08 Feb 87	2.11	2.11	CZp=133;CHp=83;UCp=101;AGp=142 CZo=63;CHo=167;UCo=76;AGo=109	Ave(p)=115 Ave(o)=104;(Cp/Co)ave=1.11
23 Feb 87	0.52	0.52		
18 May 87	0.54	0.54		Summer winds
02 Sep 87	0.38	0.38		
25 Sep 87	0.46	0.46		
22 Oct 87	0.59	0.59		Climate background low?
27 Oct 87	0.65	0.65		
23 Feb 88	0.42	0.64		Multiplied rd by 4 for traction materials
24 Feb 88	0.47	0.78		
25 Feb 88	0.48	0.86		
26 Feb 88	0.39	0.70		
27 Feb 88	0.92	1.42	CZp=133;CHp=86;Mp=70;AGp=148 CZo=94;CHo=141;Mo=119;AGo=168	Ave(p)=109 Ave(o)=131;(Cp/Co)ave=0.84
29 Feb 88	0.37	0.58		Multiplied rd by 4 for traction materials
18 Mar 88	0.39	0.61		

Date	Original Cp/Co	Modified Cp/Co	Other Stations	Comments
12 May 88	1.37	1.37		Summer Conditions
16 Jun 88	0.55	0.55		
29 Aug 88	0.59	0.59		
15 Dec 88	0.63	0.63		
06 Feb 89	0.68	0.96		Multiplied rd by 4 for traction materials + ws curtail 0.5
07 Feb 89	0.68	0.96		
08 Feb 89	0.50	0.55		Multiplied rd by 4 for traction materials + ws curtail 0.75
09 Feb 89	1.45	1.52		Multiplied rd by 4 for traction materials + ws curtail 0.8
15 Sep 89	0.49	0.49		Summer winds
25 Sep 89	1.82	1.82		

where the symbols mean:

CZp - Concentration predicted at Crown Zellerbach
CZo - Concentration observed at Crown Zellerbach
CHp - Concentration predicted at Country Homes
CHo - Concentration observed at Country Homes
UCp - Concentration predicted at University City
UCo - Concentration observed at University City
Mp - Concentration predicted at Millwood
Mo - Concentration observed at Millwood
AGp - Concentration predicted at Auto Glass
AGo - Concentration observed at Auto Glass
(p) - Refers to predicted quantity
(o) - Refers to observed quantity
Ave - Average also ave (as a subscript)
rd - Road dust from paved roads
ws - Wood smoke (stoves)